This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

NEDL TRANSFER
HN 1DSD 9

~~2.3.2~~
9180

ADDED TO THE
BOSTON LIBRARY
19th day of February 1867
to be returned in 14 days.

A fine of three cents will be incurred for each day
this volume is detained beyond that time.

CANCELLED
1940

PHYSICAL GEOGRAPHY.

PHYSICAL GEOGRAPHY.

115 131

BOSTON 1794. LIBRARY.

CANCELLED

BY

PROFESSOR D. T. ANSTED, M.A.,
F.R.S., F.R.G.S., F.G.S.,

HONORARY FELLOW OF KING'S COLLEGE, LONDON,
AND LATE FELLOW OF JESUS COLLEGE, CAMBRIDGE,
ETC. ETC.

PHILADELPHIA:
J. B. LIPPINCOTT & CO.
1867.

[*All Rights reserved.*]

KD 9180

HARVARD
UNIVERSITY
LIBRARY
MAR 5 1941

LEWIS AND SON, PRINTERS, SWAN BUILDINGS, MOORGATE STREET.

PREFACE.

It is the object of the present volume to enable the general reader who desires information on the various branches of physical geography, or the student who wishes to be aware of its general scope as a science, to obtain an outline of the main facts in language as simple and definite as possible.

Physical geography, regarded as a science, does not admit of being treated in such a manner as to render it light reading. It involves not only a statement of numerous facts, but a great classification of facts and much close reasoning. It is, no doubt, of deep interest, and concerns us all very nearly, but like other subjects of real importance, it needs an effort on the part of the reader to appreciate the array of facts and observations on which it is based, the labour of reducing such observations to systematic results, and the deductions drawn from the facts and generalisations.

Physical geography occupies at present a definite position as a science. This position is different from that which it occupied fifteen or twenty years ago, when the only works of importance concerning it in our language were prepared. Many of the statements and facts recorded in those volumes are of course still valuable, but the progress of discovery in various directions has rendered information more precise, and has justified inferences and conclusions sometimes very different.

The present volume does not claim to be complete. It is an outline carefully prepared, and is intended to supply a serious want. It does not profess to skim merely over the surface of the science, but neither does it pretend to fathom the depths. It contains many carefully arranged facts and statements in the various departments of physical geography, and legitimate deductions from them. In expressing these deductions, the Author has perhaps, in some cases, given his own views, without pointing out that other physical geographers and geologists have expressed and still hold different opinions. It was not his object to enter into a discussion on any subject, and he only desires that generalisations should be estimated at their true value and according to the evidence. He believes, however, that where the conclusions arrived at differ most from popular notions, they are not inconsistent with the views of those who are recognised, both in England and on the Continent, as the ablest pioneers of science.

It has been decided not to accompany this volume with maps and illustrations. The Physical Atlas, originally published by Berghaus, and admirably rendered into English by Mr. Johnston, still remains the best and most useful work of its kind. The smaller English Edition of the Physical Atlas will be found a valuable companion to the reader in making use of the following pages.

ATHENÆUM CLUB,
London, 1866.

PREFACE TO THE AMERICAN EDITION.

THE Author cannot allow the present volume to be published in America without acknowledging the great and important contributions to Physical Geography that have been made by Americans. Not only is the mapping of the Atlantic basin, first in general outline and then in detail, largely due to the observations and enquiries of Captain Maury, and the replies to his queries by intelligent ship masters, but the whole science of Hydrology has been advanced by other American investigators. To Mr. Marsh, United States Minister at Florence, we owe the admirable essay recently published, entitled "Man and Nature;" to Professor Agassiz, as an American rather than as a Swiss, numerous important memoirs, zoological and geological, while the publications of the Smithsonian Institutes, admirable as they are throughout, have been in no departments more valuable than in those that bear on our subject; and the geological reports of the United States surveys all contain important chapters concerning the physical geography of the districts examined. It must not then be supposed that if in the following pages it has been thought well not to crowd the pages with references, the work done by American and continental men of science is overlooked or neglected. The book itself is no more than a record of the present state of a science which has been advanced by many and laborious investigators, to all of whom thanks and credit are due.

D. T. A.

33, *Brunswick Square, London.*

ANALYTICAL CONTENTS.

PART THE FIRST.

INTRODUCTION.

CHAPTER I.

THE EARTH AS A PLANET.

PAGE

General outline of the planetary system. Existence of ether. Incessant and varied motions of masses of matter. Nature of the forces that affect matter. Motion, an expression of heat, light, and electricity, and convertible into one or other of them. Spherical form of the heavenly bodies. Position of the earth in the solar system. Magnitude of the earth—its superficial area and solid content. Distance of the moon. Effect of the moon on air and ocean. Distance of the earth from the sun. Results of excentricity or alteration of the elliptic orbit. Details of present and former excentricity. Revolution of the earth round the sun. Dimensions of the sun. Conservation of the equilibrium of the solar system. Relation of our solar system with part of the stellar system.

Condition of the earth's interior. Slow succession of deposits. Nature of underlying rocks. Temperature of the interior of the earth. Density of rocks and of the earth. Calculations concerning the thickness of the earth's crust. Material elements—the wide range of some of them throughout the universe. Three forms of matter—solid, liquid, and gaseous. States in which the most important elements and combinations usually

PAGE

exist. Behaviour of certain elements and combinations on exposure to heat. Elements known and employed in their simple states. Important combinations of elements. Limit of natural combinations.

Importance of oxygen gas and the part it plays in nature. Hydrogen and its combinations. Nitrogen. Chlorine. Silicium. Aluminium. Lists of elements and simple combinations. Law of definite proportions. Nature of mixtures. Importance of water in carrying on the operations of nature. Elective affinity. Cause of change in the materials forming the earth's crust. Limitation of physical geography and divisions of the subject . 1

CHAPTER II.

PHYSICAL FORCES.

Force of gravitation. Force of cohesion. Particles of matter never in actual contact. Chemical action. Vital energy. Convertibility of motion and heat—various illustrations of this. Aerolīths. Quantity of heat generated by the same amount of force invariable. Result of impact. Calculated result of impact of planets with each other or with the sun. Nature of heat as a form of motion. Unusual conditions of the action of heat. Conduction of heat by different bodies. Conduction of electricity. Development of heat by passage of an electric current. Probable nature of the motive power developed by electricity. Nature of light. Complex condition of rays from the sun. Oscillations and vibrations only appreciated by the senses within certain limits. Difference between waves of light and waves of sound. Transparency to light and heat not identical. Example of ice and water as contrasted with glass and air. Water not transparent to heat. Important consequences of this fact. Absorption and radiation of heat by vapour in the atmosphere. Absorption of rays which are emitted by bodies not transparent to heat (*diathermic*).

Chemical action a form of motion. Its action in combination and decomposition. Electricity developed by heat. Electricity produces magnetism. Relations of vital force with the other chief forms of force. Indestructibility of force. Importance of a knowledge of physics to the student of physical geography. Nature of polar forces. Magnetism and dia-magnetism. Position assumed by a suspended magnet. Variation of this position. Lines of no variation. Deflection of the needle. Variation of the magnetic intensity. Magnetic storms. Aurora, borealis and australis 18

CHAPTER III.

THE SUCCESSION OF ROCKS.

PAGE

Geology necessary for the study of physical geography. Use of palæontology. 1. *Rocks and their super-position.*—Composition of rocks. Fundamental rock. Granite not a simple rock. Varieties of granite. History and position of granite. Fissures in granite and mineral veins. Value of granites. Circumstances under which the granites have been formed. Water present in granites. Trap and basalt. Basalt an ancient lava. Stratified granite or gneiss. Schists—their nature and origin. Slates and their origin. Slates exhibit results of squeezing. Rocks overlying the slates. Mechanical accumulations and results of organic life. General uniformity of material of which the earth's crust is made up.

2. *Order and disturbance of stratification.*—Stratification due to water. Position in which strata have been accumulated. Impossibility of their being visible if it had not been for much and frequent breaking and lifting of deposits. Probable history of the change, and result of denudation. Results of upheaval. Absence of definite order of minerals in all stratified deposits. Identification of strata by their organic contents. Earliest forms of organic existence. Nature of the succession of rocks as indicated by fossils. Absence of proof of continuous history by advancing types. General sub-division and grouping of rocks. Nature and meaning of the principal groups. Indications of time. Sub-divisions of the older or palæozoic group. *Laurentian*, *Cambrian*, and *Lower Silurian*. *Upper Silurian* and *Devonian*. *Carboniferous system*. *Permian rocks*. Limestone, sandstone, and clay, and modifications of them, with numerous conglomerates, all found among palæozoic rocks. Their sequence determined by fossils.

Secondary or mesozoic rocks. Prevalence of limestones during this period in many parts of the world. *New red sandstone*. *Lias*. *Oolitic series*. *Wealden*. *Chalk*. Interval between secondary and tertiary rocks. Distribution of minerals among tertiary rocks of Europe. Surface deposits of gravel, sand, and boulders. General conclusions concerning the succession of rocks and their relation to successive forms of life.

3. *Metamorphosis.*—Nature of the changes that have affected rocks. Forces that have acted to produce these changes. Influence of water in producing change. Absence of evidence of melting heat affecting stratified rocks. Modifications of limestone. Metalliferous ores found in limestone. Water the cause of such results. Clays as aqueous rocks. Conversion of clays into shales and slates, due to water. Filling of veins and slates, a result of water action. Granite as connected with water. All granitoid

PAGE
rocks formed with water. Quiet nature of change and general absence of catastrophes. Circulation and movement in the interior of the earth not inconsistent with outward tranquillity. Conclusion that there has always been a circulation of water reconstructing and reproducing, as well as destroying and wearing away the various rocks 32

PART THE SECOND.

EARTH.

CHAPTER IV.

LAND.

Irregularity of the earth's surface. The actual state of the surface liable to change. Present configuration, that most important to us. Grouping of land into continents and islands. Dimensions of tracts of land very variable. Position of land very peculiar. Preponderance of land in one hemisphere. Inquiry if there is any cause for such difference. General statement of distribution of land. Position of the hemisphere of maximum land. Nature of the protuberance producing excess of land in one hemisphere. Speculations concerning the cause and permanence of this protuberance. Determination of oceans by the position of the land. Relative smallness of the depth of water and height of mountains. Smallness of the average slopes leading to the highest and lowest points. Importance of irregularities of surface on climate. Distribution of the land. High and low plateaux, and plains near the sea. Deep gorges contrasted with mountain chains. Valleys, as distinct from mere gorges. Form and area of land liable to change. Possible origin and extent of such change. Limiting line of sea and land. Advantages of a broken coast line.

Natural irregularities of the surface of the land. Continents and islands. Islands parts of submerged continents. Position of the great continent. Dimensions of the great continent. Fringes of islands. Pyramidal termination of the land. Illustrations in various parts of the world. Total length of the geographical axis of the old world. Direction of this axis. Influence of its direction on climate. Details of coast lines. Europe and Asia one continent. Extended coast line of Europe.

PAGE

Proportion of area to each mile of coast. Coast of Asia considered alone and with Europe. Proportion of area to a mile of coast in each case. Coast line of Africa. Large area to each mile of coast. Inference from this fact. America and its coast. North America compared with South America in the proportion of area to each mile of coast. Australian coast line and its proportion to the whole land. Advantage of a broken line of coast.

General nature of the land. Plateaux or high plains of Europe and Asia. Steppes of Russia. Low plains and valleys. Rivers and waterfalls. Fewness of torrents and waterfalls. Absence of many large lakes in Asia. African mountains and plains—its lakes and rivers. American features—its mountain chains and rivers. Australia—its level surface and absence of mountains and rivers, in proportion to its magnitude.

Islands—their general nature. Different origin of islands. Indian Archipelago. Grandeur of some of the islands. Vast multitude of islands of moderate dimensions. Islands of the South Pacific—extent of submerged continent indicated by these islands. The case of coral islands as bearing on the history of islands. Large extent of submerged area. Islands indicate the ancient history of the earth.

Direction and amount of the slopes of lofty mountain chains. Difference of the steepness on the two sides. Position of culminating points of mountain chains. Depressions in oceans probably correspond to mountains on land. Contrast between Europe and America as mountainous countries. Plains are characteristic of America. Great rivers and lakes also remarkable features of that continent. Australia, the land of unwatered plains. Certain groups of islands rise to some culminating point.

Connecting link between physical geography and geology. Theoretic views of the earlier geologists. Supposed great energy of forces in ancient times not proved. No evidence of the first introduction of life. Nature of the development that seems traceable in the preparation of the earth. Enormous denudation not sufficiently taken into account. Ages of the great mountain chains. Absence of any definite limits of land and water. Absence of clue to the first condition of the earth . . . 57

CHAPTER V.

MOUNTAINS.

Importance of mountains in physical geography. Only two great mountain axes. Great elevation not the only essential. The two independant chains. Details of the great mountain system of the Old World. Alpine system—its characteristics. Eastern division—width of the chain. Effect of denudation on the Alps. Pyrenean chain—subdivisions. Glaciers of the Pyrenees. Carpathian mountains. Dinaric Alps. Balkan range. Greek

PAGE

mountains. Apennines. Scandinavian mountains. Mountains of the British islands. French mountain systems (Cevennes and Vosges). German mountain groups (Fichtelgebirge, Hartz, Erzgebirge). Mountains of the Iberian peninsula (Sierras Nevada, Morena, Estrella, &c.). Crimean mountains. Ural chain. The Caucasus. Taurus and anti-Taurus.

The mountain systems of Asia. Hindoo-koosh. Himalayan chain. Altai mountains. Extension of these chains eastwards. Highest elevations. Thian-shan. Magnitude of the chain. Kuen-lin. Mountains of Arabia. Vindhya mountains and Ghâts of Hindustan. Mountains of the Malay peninsula.

Mountains of Africa. General distribution. Atlas mountains. Mountains on the east coast. Kilima-njoro and Kenia. Abyssinian mountains. Connection with the mountains of Arabia.

American system. The main outline. Rocky mountains. Snowy mountains and Black hills. Oregon chain. Mount Elias. Cordillera of the Andes. Central American or connecting group. Subdivision of the Andes. Andes of Patagonia, and Chilian Andes. Bolivian and Peruvian Andes. Andes of Quito and New Granada. Mountains of Brazil. Alleghany and Catskill mountains.

Australian mountains. Main chain. Australian Alps and Mont Kosciusko. Extension into New Guinea. New Zealand mountains. Lofty summits and glaciers. Mountains a result of long-continued elevation and denudation 74

CHAPTER VI.

HILLS AND VALLEYS. PLATEAUX AND LOW PLAINS.

1. *Hills.*—Definition. Distinction between hills and mountains. Examples. Hills at a high level and mountains near the sea. Position of hilly ground. Rolling ground and its probable origin. Malvern Hills, Cotteswolds, and South Downs. Waldai Hills. Transfer of table land into hill country. The Saxon Switzerland and the Quantock Hills. Franconian Switzerland. Origin of hills in such districts as those just referred to. Important influence of denudation.

2. *Valleys.*—Different conditions of valleys according to geographers. Fine scenery in upland valleys in mountain countries. Valleys, indications of progress. Varieties of valleys according to geologists. Construction of valleys. Modification of natural fissures and gorges. All valleys more or less produced by erosion. Origin of valleys of erosion in some places. Illustrations of lower valleys. Valleys of Rhine and Danube. Valleys of Asiatic and American rivers. Use of valleys in advancing civilisation.

3. *High Plains.*—Limitation of the term *plateau*. Peculiarities of lands thus named. Their relation to geological structure. English plateaux of chalk, oolite and granite. French plateaux

PAGE

of limestone and basalt. North German plateau. Carpathian plateau. Central plateau of Spain. *Sierras* rising through it. Extension of Iberian plain into Portugal. Asia, the country of plateaux. Plains of Arabia and Persia. Plains of Armenia. Salt desert of Persia. Table lands of Tibet. Deserts of Gobi and Scha-mo. Their extension and elevation above the sea. Other plateaux of Tibet. High lands of the peninsula of India. Plateau of the Deccan. Table lands of the Faro islands—and of the British islands. Table lands of Africa. Southern plateaux. High plains of Australia. North American plateaux. Great basin of California. Plateaux of Central America—of South America. The Desaguadero. Patagonian steppes. Tabular statement of the levels of plateaux.

4. *Low Plains.*—Definition. Low plains of northern Europe. The Kirghis steppes and Siberian plain. Aralo-Caspian plain. The steppes of Russia described. The great plains of northern Asia. Plains of Hindustan. African plains. The Sahara. Desert of Arabia. Low plains of Central Africa. North American plains. Prairies, Savannahs, and pine-barrens. South American plains. Llanos and Silvas. The Pampas. Step-like terraces. Australian plains. Deltas of rivers. Strips of low land on coast lines of South America. Comparison of Old and New World in the matter of plains. Importance of low plains to human requirements. Low plains, in reference to vegetable and animal life. Ethnological value of low plains 97

PART THE THIRD.

WATER.

CHAPTER VII.

THE OCEAN.

Importance of water in the economy of the earth. Nature of the barriers that enclose the ocean. Division into two great oceans. Atlantic canal—its dimensions and proportions—its subsidiary or inland seas on the European side. Inland seas on the American side. Islands. Dimensions of the Pacific Ocean. Its inland seas. The Indian Ocean. The Arctic Ocean. Antarctic Ocean. Natural subdivisions of the great ocean by submarine mountains, forming islands and shoals. Northern and southern basins of

PAGE

the Pacific. Subdivisions of these. Subdivisions of the Atlantic. Northern, central, and southern basins of the Atlantic. Inland seas and their formation. Necessity of a knowledge of the ocean floor. Methods of sounding in great depths. Old and modern methods. Results of deep sounding with a deep-sea dredge. Material at bottom of the Atlantic. Nature of the *oaze*. Form of bottom of the Atlantic. Bottom of the Pacific. Bottom of the Indian Ocean.

Composition of sea water. Origin of saltness of the sea. Various amount of salts in different seas. Atlantic more salt than Pacific. Position of the belt of saltest water in the Pacific. Smallness of salt in the Polar seas. Usual proportion of saline substances. Nature of the ingredients of sea water. Names of elements found. Variation of density of sea water in different seas. Atlantic, Pacific, and Indian Ocean compared. Density of Mediterranean water—Black Sea—North Sea—Baltic. Chemical contents in ordinary sea water. Local differences. Gases and air in sea water. Uses of air in water. Effect of cold on density of water. Capt. Maury's experiment, illustrating the conditions of cooling sea water. Circulation of the waters of the ocean. Temperature of the sea. Stratum of invariable temperature. Pressure of the water. Animal life at great depths. Limitation of life in deep water not known. Light the only limit. Colour of sea water. Blue grotto of Capri. Cause of blue colour of water. Different colours of the water in different seas. Colour of the Black Sea.

The water of the sea always in motion. Various kinds of waves. Different kinds of motion of water. Wind-waves, their nature and origin. Growth of wind-waves into storm-waves. Ground swell. Surf. Mechanical force of storm-waves. The tidal wave —its origin and history. High and low water. Conversion of the tide-wave into an advancing wave. Great rise of tide in certain waters. Marginal and local tides. The *bore*. Nature of the motion of the tide-wave. Transference of motion without the removal of the body of the water. Different kind of currents. Stream currents—their origin. Various causes that may produce them. Effect of evaporation in narrow seas. The Red Sea current. Under-currents carrying back the water. Periodical currents.

The Gulf stream—its commencement and course—its position and condition in the Atlantic—its temperature—its derivation from the equatorial current. History of this current and its counter-current running to the Guinea coast. The Brazil current—its nature, depth, and temperature. Rennel's current. Arctic or Polar current. United States counter-current. Antarctic current. South Atlantic current. The Pacific currents. Black stream of Japan. South Polar current. Mozambique current. Humboldt's current.

Eddies and whirlpools. Maelström. Charybdis. Origin of such eddies. Sargasso, or weedy seas. North Atlantic sargasso sea. North Pacific sargasso sea. Nature of such seas. Extension of the sargasso or gulf weed into British seas 125

CHAPTER VIII.

RIVERS.

PAGE

Circulation of water on the earth by aid of the atmosphere. Natural course of running water on the land. Uses of rivers. Largest and most rapid rivers not the most useful. Advantage of moderate rivers. Drainage systems. Water-sheds and water-parting. Water-shed not necessarily a ridge. Sources bear no proportion to the rivers. Difficulty of discovering the real sources of rivers. Absence of importance of this inquiry. Sources of the Nile. The great river systems sometimes connected. Example of Amazons and Orinoco. Rivers generally originate near mountain chains. Rapidity of streams not altogether dependent on height of source. Streams of all kinds assist in denudation.

River systems—how best considered. *The Atlantic system.* Vast importance of the streams draining into the Atlantic. Absence of streams on the Scandinavian shores. Important feeders of the Baltic; Neva, Niemen, Vistula and Oder. Extent of land drained by these rivers and their tributaries. Rivers entering the German Ocean. The Elbe and its tributaries. The Weser. The Rhine: its sources and tributaries. Its delta. Its total length of course and drainage area. The river systems of the British islands. The French rivers—the Seine and Loire—the Garonne. The rivers of the Iberian peninsula. The Douro and the Tagus, the Guadiana and the Guadalquivir. Extent of area drained.

The Mediterranean basin and the rivers draining into it. The Ebro. The Rhone and its tributaries. Its drainage area. Italian rivers—the Arno and Tiber on the west—the Po and Adige on the east. Area drained. The Black Sea. The Danube and its tributaries. The Dniester and Dneiper. The Don and Kuban. The Nile and its course. The Niger and Senegal. The Orange river, the Gambia and the Coanza.

The great river systems of America. The Plata and its main branches. The Amazons and the various names of its different parts. The Orinoco. The Magdalena. The Rio del Norte. The Mississippi-Missouri and its great tributaries. The smaller rivers of the United States. The St. Lawrence and its lakes.

The Pacific system. The African rivers Zambesi and Great Fish river. The Tigris and Euphrates. The Indus. The Ganges and Brahmapootra. The Irawaddy. The great rivers of China. The rivers of Tartary. The rivers of America entering the Pacific. The rivers of Australia. The rivers entering the Arctic ocean. European and Asiatic streams. North American streams.

Internal drainage. *Caspian Sea.* The Volga, Ural and Kur. The sea of Aral and the Sir. Tabular statement of the principal systems of drainage. Large parts of the earth left undrained by the great river systems. 149

CHAPTER IX.

LAKES AND WATERFALLS.

PAGE

1. *Lakes.*—Their nature—mode of formation—varieties—cause of varieties. Tarns. Permanent and changeable lakes. Difference between lakes and ponds. Examples of lakes and pools. Salt lakes once part of the ocean. Deposits of salt formed in salt lakes. Lagoons, sometimes formed by mud. Proportion of the land covered with water. Estimate of the total area of lakes. Proportion of fresh and salt water lakes. English lakes—their names and proportions. Scotch, Irish and Welsh lakes. Absence of lakes in France. The lakes of the Alps. Swiss lakes:—lake of Geneva—lake of Lucerne—lake of Zurich—lake of Wallenstadt—lake of Constance—lakes of Neuchatel and Bienne. Italian lakes:—Lake of Como—Lago Maggiore—Lake Lugano—Lago di Garda. Rivers issuing from the Swiss and Italian lakes. Comparison of the lakes on the two sides of the Alps. Lakes of the Pyrenees. Lakes of Northern Europe. Wurm-see, in Upper Bavaria. Ammer-see.—Chiem-see.—Neusiedler-see.—Platten-see. South Italian lakes.—Lakes Thrasymene, Bolsena, Vico and Albano. Lakes of northern Europe. Swedish lakes,—Wenern, Wettern, and Mälar. Lake Hielmar and Lake Barken. Finland and its lakes on the central plateau. Lakes Ladoga, Onega, Saima, and Ilmen. Lake Enare in Lapland. Lakes near the Arctic Ocean. General Character of the north European lakes.

Aralo-Caspian depression and the Caspian Sea. Fresh water lakes of northern Asia. Lake of Baikal. Drainage of this lake. Lakes of western Asia. Tengis, Tehany, and the Persian lake Urumiyah, Lake Van, in Armenia, and Lake Seistan in Iran. Smallness of the lakes in Asia, south of the main mountain chain. Depressed basins as distinct from mountain lakes. Details of the Caspian Sea. The Sea of Aral. The Dead Sea and its peculiarities. Lakes of Africa. Victoria Nyanza, one of the head waters of the Nile. Its connection with Albert Nyanza. Details of Albert Nyanza. Lake Tanganyika. Lakes Nyassa and Shirwa. Lake Tchad,—its peculiarities and difference at different seasons. Australian lakes.—Lake Torrens and Alexandrian lake. North American lakes. Great Bear and Great Slave lakes. Athabasca, Wollaston and Deer lakes. Winnipeg and Winnipegoos. Lake Superior. Lakes Huron and St. Clair. Lake Michigan. Lake Erie. Lake Ontario. Total area of the North American great lakes. Difference of level of these lakes. Lake Champlain. Lakes in Florida. Lake Pontchartrain. Central American lakes. Nicaragua. South American lakes. Lake Titicaca. Lakes in Brazil. General conclusions as to the nature of lakes.

2. *Waterfalls.*—General account of rapids or waterfalls. Such phenomena not universal with large bodies of water. Falls of the Rhine. Cascades of Switzerland. The Handek and the

PAGE

Staubbach. The Norwegian Falls.—Sarp-fos, Riukan-fos, and Vōring-fos. The Ostud-fos. Rapids. Former rapids of the Rhine and Danube. African water-falls. Falls of the Zambesi described by Livingstone. Ripon Falls and Murchison Falls of the Nile, described by Speke and Baker. American falls of Niagara. Details of these falls. Differences of level and body of water estimated. Falls of Kakabika. 169

CHAPTER X.

THE PHENOMENA OF ICE.

The properties of ice very different from those of water. Formation of snow in the air. Mode of crystallisation of snow. Snow in stars and pellets. Snow formed in the upper air in all parts of the world. Cause of this explained. The *snow-line*, explanation of the term. Position of the snow-line in Peru, in western Africa, in the Himalayan mountains and in the Andes. Difference of height in different latitudes and climates. Snow-line in Atlas mountains, in Sicily, and in the Alps.—In Norway and in the Arctic circle. Difference between southern and northern hemisphere in the position of the snow-line. Cause of this difference. Limits of snow at the sea line in the western and eastern parts of the old world. Local absence of snow in certain sheltered spots. Number of days of snow-fall in different climates. Average at Rome—at St. Petersburg. Large falls on the east coast of North America. Snow not injurious to vegetation.—Condition of fallen snow. Hail—its nature. How and when formed. Large hail stones. Paths of hail stones. Narrow breadth of country generally injured by hail. Places where hail is most common.

Ice expands during formation from water. Cause of this expansion. Pressure tends to prevent the formation of ice. Difficulty of forming ice at great depth in water. Purity of ice. Result of the expansion of water while becoming ice, in preventing a great thickening of ice on a body of water exposed to intense cold. The sea less readily frozen than fresh water. Formation of pack-ice from snow. Possible results of change in the distribution of land and water, producing what is called "perpetual snow," over large tracts. No real "perpetual snow." Mode in which mountains are relieved of their load of snow. Formation of a tongue of ice beyond the snow, and deeper in valleys than the snow-line. Movement of this ice and formation of a glacier. *Névé*, or *Firn*, the feeder of the glacier. Process by which *névé* or glacier ice is formed. Mode by which it is increased in the course of years and rendered uniform. Essential conditions for a glacier. Kind and rate of its motion. Winter cold penetrates but a little way. Imperfectly formed glaciers. Glaciers rent by fissures. Water passes through these. Production of streams

PAGE

of stone at the surface called *moraines*. Production of icebergs. Increase of glaciers by successive streams of ice. Their passage over obstacles. Nature of the motion of glaciers. Ice does not move like a tenacious fluid. Property of *regelation*. Illustrations of this mode of behaviour of ice. Example in snow pressed and squeezed in a ravine. Result of pressure on the bottom and sides of the ravine resembles that of solids. Effect in known cases illustrated in the Alps. The Alps not the only places where evidence of this kind is to be obtained. Examples in New Zealand,—in the Himalayas,—in Norway and Greenland. Indications of glacial action far away from glaciers. Examples in the British islands, in Northern Europe and North America. Examples in Asia Minor.

Icebergs—their nature, mode of formation and proportions. Great depth below the surface of the sea. Result when melted. Icebergs not easily seen and studied at sea. Time when they are most numerous in the Atlantic. They advance less towards warm latitudes in the southern hemisphere. Their appearance when seen under favourable circumstances. Their colour, changes of form, and frequent change of position.

Ice formerly advanced much further over the northern hemisphere than it now does. Nature of the proofs of this statement. Periods of cold existed in much earlier times in the world's history. Proofs of this seen in smoothed and striated rocks beneath old deposits. Permian and old red sandstone glacier periods possible. Theory of a uniform ice-cap alluded to. Condition of the planet Mars in reference to this theory . . . 188

CHAPTER XI.

SPRINGS.

Disappearance and history of the part of the rain-fall that neither runs off the earth's surface nor is evaporated. Passage of such water through rocks. Its issue above the sea level. Occasionally brought back again into circulation. Water rising out of the earth called spring water. Various kinds of springs. Land springs in open rocks. Quality of the water obtained from them. Natural purification of water. Absorption of water into strata. Nature of Artesian springs and wells. Meaning of the term Artesian. Springs in fissured rocks and at faults. Course of water under such circumstances. Limestone districts rich in springs of this kind. No spring water chemically pure. Substances generally present in spring water. Water with very small quantities of foreign substances, in France and Germany. Other waters with large quantities. Mineral springs common in volcanic regions. Example at Carlsbad. Springs at contact of two rocks. Long lines along which mineral springs occur. Distribution of springs in central France, near a volcanic district now

PAGE

extinct. Universal presence of mineral springs. Number of those described in France and Spain. Quantity of water issuing from certain springs. Examples at Carlsbad, in Switzerland, in the Pyrenees and in North America. Large springs in central France. Water issuing at the surface much less than the quantity actually lifted. Dissipation of strong springs. Example of springs not reaching the surface.

Temperature of mineral springs. Boiling springs near volcanoes. Springs in the Pyrenees. English thermal springs.

Contents of mineral waters. Water an almost universal solvent. Chemical conditions of solution. Inorganic acids and bases most commonly met with in waters. Result of spectral analysis. Organic acids occasionally found. Large quantity of solid matter thus removed from the interior to the surface. Quantity of carbonate of lime and silica especially large. State of the substances held in solution important. Examples in various cases. Abundance of sulphur. Various forms of sulphur and results. Fluorine and phosphorus common in certain springs. Boracic acid occasional. Distribution of silica very general. Deposits of silica from springs. Carbonic acid especially common. Hydrocarbons also common in certain cases. Bituminous springs in various parts of the world. Bitumen often associated with common salt. Potash, soda and lithium, as existing in mineral waters. New metals found in them. Vast quantity of carbonate of soda sometimes present. Deposits of sulphate of soda. Deposits of carbonate of lime. Successive crusts of carbonate of lime broken through at Carlsbad. Deposits of gypsum. Salts of magnesia very common in certain waters. Alumina combined with silica and other elements common in spring waters. Metals commonly found. Manganese and iron. Quantity of iron in certain springs in the Eifel. Cobalt and nickel in water. Copper, lead and silver known, or probable. Organic matter as *glairine* or *barégine* found in certain mineral waters. Abundance of vegetable growth in the waters at Plombiéres.

Changes in the quantity and condition of the waters issuing from certain sources. Effect of earthquakes on springs. Example in the great earthquake of Lisbon. Intermission of water in certain springs. Syphon springs—peculiarities of discharge of water in certain cases. Intermission in a spring at Kissingen. Observations spread over six years, and results. Variations of springs at Vichy and the Pyrenees. Special conditions on which the change is supposed to depend. Change in the gaseous contents of spring waters occasional. Periodical deposits by the water of certain springs.

Great influence of water on all rocks. Metamorphism thus effected. Fossilization also produced. Water the means by which chemical action is exerted. No probability of an independant source of water in the earth's interior 201

PART THE FOURTH.

AIR.

CHAPTER XII.

THE ATMOSPHERE.

PAGE

Composition of pure dry air. Elasticity of the air. Pressure of the air at the sea level and at great heights. Height of the mercurial column at various elevations. Estimated height of the air if it were not elastic. Calculated weight of the atmosphere of pure dry air. Aqueous vapour mixed with pure dry air. Other substances commonly present. The gases that form atmospheric air not chemically combined. The proportions of oxygen and nitrogen uniform under all circumstances. Absence of satisfactory explanation of this uniformity. Great changes in pressure of the air on the same level. Oscillations of the barometer regular and occasional. Maxima and minima of daily oscillations. Seasonal oscillations. Regularity of such movements in certain parts of the world. Extent of range small.

Effect of heat on the atmosphere. Mode in which air is heated, not by radiant heat, but by conduction. Heating of air by compression and cooling by expansion. Different temperature of boiling water at various pressures. Estimate of the height of mountains by the temperature at which water boils. Diminution of temperature in ascending to the upper part of the air. Cause of this change. Rate of diminution as estimated by Mr. Glaisher. Occasional exceptions.

Relations of air to light. Absorption of light by air entering at various angles. Reflection and absorption of rays in passing through the atmosphere. Refraction of light in passing into and through the air. Form of a ray of light passing through the atmosphere. Partial absorption of coloured rays. Statement of the course of a ray of light in the air. Result of the dispersion and reflection of light in the air. Absence of sudden transitions from light to darkness. Twilight—cause of its different duration at different places and seasons. Appearances of the sky at various parts of the day. Limitation of twilight as produced by reflection. Effect of the presence of aqueous vapour on refraction. Production of optical delusions, or *mirage*, by complicated refraction and reflection in the air. Examples of mirage. Causes of the more striking phenomena suggested. Simple cases of re-

PAGE

flection. Vertical and horizontal reflections. Suspension or *looming*. Strata of the air at different temperature the main cause of such appearances. Calm essential to irregular refractions.

Colour of the atmosphere. Cause of the azure colour. Water and aqueous vapour largely affect the colour of the air. Colours of the clouds. Rainbow. Phenomena of the rainbow described and the cause explained. Rainbows in waterfalls.

Waves produced in the atmosphere. Sound the result of such waves. Loudness independant of the velocity of the waves. Different rate of travel of sound waves. Temperature affects the rate of the wave.

The atmosphere in its relation to life. No material life conceivable without air.

Polarisation of light—its meaning. Peculiar properties of polarised light. Polarisation effected both by reflection and refraction. One of the two beams of light, emerging from a doubly refracting crystal, is polarised. Polarising angles by reflection. Part of the light always polarised. Neutral points in the sky. Antisolar points. Obscurity of this department of optical science. Important modern discoveries in the upper part of the atmosphere. Diminution of temperature. Law of diminution still undetermined. Important modification of the prismatic spectrum in the higher part of the atmosphere. Increase in the number of dark lines observed 221

CHAPTER XIII.

WINDS AND STORMS.

Cause of winds the transparency of the air to heat. Use of the term 'diathermal' in reference to this. Interruption of part of the heat rays. Proportion of heat rays received different, according to the angle at which they fall. Difference caused partly by the nature of the material on which the rays fall. Parts of the earth most and least affected by the sun's rays. Expansion of the air heated by the earth. Production of vertical and horizontal currents. Circulation of the atmosphere affected by the action of the sun on the earth. Mode in which this is produced. Proof of the existence of an upper current in the air by volcanic dust and cloud. The winds observed on the Peak of Teneriffe. The trade winds—their meaning and value. 'Horse latitudes' of sailors and south-west passage winds. Comparison of the southern and northern trades in the Atlantic. Explanation of the fact that the south-east trades are the most steady. Modifications of the trade winds in India and on the plains of Central Asia. Monsoons, their nature and history. Their difference from trade winds. They replace the trade winds as regular winds in the seas they occur in. The north-east monsoon, its chief peculia-

PAGE

rities. South-west monsoon. Change from one to the other marked by storms. Trade winds not always east winds, and more to be trusted on the western than on the eastern shores of a large sea. The trade winds confined to the ocean, but replaced by steady land winds. Effect of permanent winds on the land.

Storms of three kinds, viz.—wind storms, electric storms, and magnetic storms. Lightning and thunder. Circumstances under which electric storms occur. Account of forked and sheet lightning. Cause of the different phenomena. Limitation of thunder storms. Peculiar effects during such storms. Magnetic storms unaccompanied by noise. Auroræ, common indications of atmospheric disturbance. Circular progress of severe storms. "Royal Charter" storm of October, 1859. Remarkable meteors and auroral discharges about the same time all over the world. Disturbance of the telegraphic wires. Velocity of the wind in the storm. Direction in which the storm crossed Europe. Cyclones and cyclonic storms described. Details of a cyclonic storm described by Admiral Fitzroy 236

CHAPTER XIV

DEW, CLOUDS, AND RAIN.

The conditions of aqueous vapour in the air important to be understood in reference to the history of dew, fog, mist, cloud, rain, snow, and hail. Aqueous vapour not diathermic (transparent to heat). It is diffused through air, of which the mass is much greater, and before it cools the surrounding medium must be cooled. Solids cool rapidly by radiation, and thus vapour is deposited as dew. Dew explained long ago by Dr. Wells. Results of radiation into a clear sky. Results of check to radiation. Effect of radiation diminishes with extreme rapidity at a small distance from the radiant. Great difference of temperature on grass and a few feet above it. Condensation of aqueous vapour as mist or fog. Cause of this explained. Air chilled by contact with high land. Formation of fog.

Definition of cloud. Characteristics of clouds. Work done by clouds, and their use and advantage in the economy of nature. Where clouds form. Clouds over forests after rain. Clouds forming over valleys. Elevation of clouds. Course of clouds on the Peak of Teneriffe. Mechanical difficulty involved in the formation of cloud. Quantity of water in a cubic yard of air at a certain temperature. Source of the vapour that passes into the air. Tendency of vapour to assume the form of the object by which it is caused. An immoveable cloud formed on the top of a mountain by a drifting wind. Such a cloud a driving mist. Clouds forming half way up a mountain side. Tendency of a cloud once formed to remain suspended in mid-air. Different kinds of clouds thus formed are characteristic. *Cirrus* clouds—

PAGE

their origin, form, colour, and grouping. The phenomena of broken light derived from them. Iridescent character of such clouds. Occasional production of parhelia or false suns. Passage of the cirrus into the *cirrostratus.* Horizontal and diverging bands of cloud. *Cumulus* clouds—how formed and got rid of. Grotesque and varied forms of these clouds. *Cumulo-stratus* clouds—their relations to the cumulus. Rain cloud (*nimbus*). Ragged form and sweeping outline. Nearness to the earth. Appearance of sweeping motion often false. Fanciful appearances taken by clouds. Description of rain clouds by Ruskin. Motions of clouds. Fantastic forms of clouds indicating change of weather. Examples of permanent cloud with a varying wind. Clouds coming up against the wind. Colours and shadows of clouds. Causes of colour in clouds. Varieties of colour in clouds.

Floating of clouds in the air. Mode in which clouds are suspended in the air. Nature of the vapour-atmosphere. Mode in which two gases mix without reference to their specific gravity by diffusion. Similarity of condition in the case of the vapour atmosphere within the atmosphere of dry air. Dr. Tyndall's researches in this direction. The resumption of the visible form the most difficult part of the subject to explain. Conversion of mist into dry cloud. Disturbance of electric equilibrium in such cases. Formation of drops of rain. Change from invisible to visible vapour not always accompanied by electric action.

Phenomena of rain as seen in the tropics. Quantity of rain thus falling. Extreme cases of rain-fall in India. Extreme rain in any one day in the tropics. Account of the rain-fall in temperate latitudes. Cause of rain in these latitudes. Average rain-fall on the western shores of Europe. Enormous rain-fall in England in certain places. Contrast with other parts of the country at no great distance. Mean annual rain-fall of the British Islands, and of each natural division of the country. Rain-fall in various parts of England. Dependence of the average on local conditions. Time of greatest rain in the British Islands—and of least rain. Months where there is greatest rain. Condition of other countries as compared with England. Condition of the interior of Asia and Africa as compared with England. The deserts and the rainless districts of the western coast of South America. General result of change of geographical condition on the rain-fall and on the distribution of rain.

Physical force exerted in the conversion of water into vapour and the converse. Estimate of this force. Estimated rain-fall on the earth. The rain regarded as representing the heat received on the earth from the sun. Cloud and mist do not necessarily precede rain. Phenomena called *serein*, and its cause. Total annual rain-fall on the different natural divisions of the earth estimated. Mode in which the rain thus falling is got rid of . 246

CHAPTER XV.

CLIMATE AND WEATHER.

PAGE

Nature of climate. Causes that produce climate. Importance of heat. Distribution of heat different in different places. Mode of estimating the heat at a station. Nature of the averages. Times when the temperature is nearest the daily average. Mean annual temperature. Isothermal lines, or lines drawn through places having the same mean annual temperature. How the mean annual temperature is made up. Effect of the sun in producing and modifying the range of daily temperature. Average daily, monthly, and annual mean ranges. Mode of distribution of heat. Dependence of the healthy state of the atmosphere on temperature. Estimate of range of temperature. The daily range how obtained. Difference in different parts of the country. Actual average at Greenwich. Illustration of the meaning of range of the thermometer and the value of averages. The senses do not always agree with the thermometer indications. Temperature only one of several elements of climate.

Pressure of the air as affecting climate. Elasticity of the air. Sensitiveness of the human frame under certain circumstances. Position important as influencing prevailing winds. Character of particular winds. Dependence of this on position. Prevailing winds to be alluded to in describing climate. Result of opposing winds near a coast. Climate of England produced by its position. Rain-fall as affecting climate. Cloud in its influence on climate. English climate not on the whole unfavourable. England remarkable for frequent change. Favourable influence of island climates on vegetable and animal life generally. Electrical state of the air an element of climate. *Ozone*—its meaning. Want of ozone unfavourable to health. Advantage of vicinity to ocean. Islands generally more healthy than continents. Many climates in one country. Climates of different countries. Changes in the physical features of a country involve changes of climate. Consequences, were the Gulf Stream to change its course. All such changes independent of any change of mean annual temperature. Animal inhabitants and vegetation might, however, be greatly altered. Incessant change in all respects the law of nature. Climate also changed by human influences. Changes thus produced in England.

Weather.—Definition. Constantly shifting. Chief peculiarities of weather. Fine season. Cycles and periods of fine weather. Bad weather the converse. Average of weather is climate. Climate may change, but weather must change. Weather may be uniform over wide tracts having different climates. Example in 1842. Weather different on the two sides of a mountain chain. Calms in the midst of storm. Cyclones. Meaning of change of the

PAGE

weather. Various weather indications. Clearness of outline of distant objects. Appearance of the clouds. Various meteors. Passage of light into massive clouds. Alteration of form or other appearance of clouds indicative of coming change. Various strata of air under very different conditions. Rising of smoke in the air. Direction of wind, and of change of wind. Easterly winds and their nature in our climate. Their characteristics. Habits of animals and conditions of vegetation and human sensations. Instruments used to record the differences of the state of the air that produce these indications. Barometer—what it is and what it teaches—what is required to give it value as a weather-gauge. Nature of barometric observations. Comparison of barometric with thermometric changes. Observations concerning the direction and force of the wind. Backing of the wind an indication of bad weather. Auroral appearances unfavourable. Magnetic storms.

Peculiarities of weather, even if continued, do not involve permanent change. Cycles of weather occur. Foretelling weather always uncertain. Ordinary indications fail to tell us of changes some time distant. Rules from experience very valuable. All guesses at weather result from experience and observation. Important work of the meteorologist. Mutual dependence between material and immaterial parts of the creation. Influence of weather on human intellect. Climate and weather not permanently deteriorated. Weather and climate not permanent . 265

PART THE FIFTH.

FIRE.

CHAPTER XVI.

VOLCANOES AND VOLCANIC PHENOMENA.

Phenomena of volcanoes generally. Effect on the senses. Apparent magnitude and importance, and long duration. Actual limitation of the phenomena generally. Account of the crater of Kilauea (Hawaii) and the eruptions. Peculiar nature of the eruptions. History of an ordinary eruption. Example at Coseguina, in the Andes, of enormous quantities of fine dust. Masses of rock erupted. Outflows of lava. Distribution of volcanoes and number of principal cones. Number of volcanic vents in a given district unimportant. All volcanoes not directly related.

PAGE

Position of volcanoes and volcanic bands on the earth. Interference of volcanic basins. Volcanic lines on the edges of the great oceanic basins. Order of importance of the volcanic areas.

European system of volcanoes defined and described. Etna, Vesuvius and the Lipari islands. Extension of this line to the semi-extinct volcanoes of the Apennines. Volcanic action on the Apennines. Account of Etna. History of its eruptions. Connection with Stromboli. Graham's island. Vesuvius. History of eruptions. Volcanic band of the Greek islands. Eruptions of Santorin. Coincident disturbance between the Greek Archipelago and Sicily. Asia Minor and its volcanoes. The Taurus and Caucasus contain volcanic rock. Syria, the Holy Land and Arabia volcanic. Volcanoes of eastern Africa. Absence of volcanoes in northern Africa. Volcanoes in the Azores and Canary islands. Cape de Verd islands. Ascension and St. Helena. Trinidad (S. Atlantic) and Tristan d'Acunha. Interior of Africa and Australia. Icelandic volcanic group and Jan Meyen's Island. Hecla and its eruptions. The Geysers. Asiatic volcanoes of China. Islands of Asia. Volcanoes of Sumatra and Java. Branch of the volcanic belt to the Phillippines and Formosa. Extension of this line to the Kurile islands and Kamtchatka. Australian group and New Zealand volcanoes. Hawaii. Various volcanic islands in the Pacific. American system. Tierra del Fuego and Patagonian volcanoes. Chilian Andes and their volcanoes. Peru and Bolivian Andes and their volcanoes. Quito and Cotopaxi. Main branch to the West Indian islands. Guatemala group on the Pacific coast of central America. Volcanoes in Mexico and California. West coast of North America, Aleutian islands and Kamtchatka. Further continuation by the Kurile islands.

Evidence of subdued and decaying activity in certain volcanic districts. Interest attaching to this part of the history of volcanoes. Absence of evidence of the first commencement of volcanic disturbance in a new district. Meaning of the apparent diminished action. Salses and mud volcanoes instances of decaying energy. Limitation of mud volcanoes. Recent eruption of a mud volcano in Sicily. History of the eruption. Mud volcanoes of the Crimea and Taman. Groups of volcanoes of this kind recently in action. Wide range of the phenomena. Mud volcanoes of northern Italy. Subdued volcanic action in Java and in Mexico. Other cases in the West Indian islands, in California, and in Iceland. Nature of the material erupted. Variety of material of mineral springs in different places.

Limit of distribution of volcanoes further considered. Vicinity of the sea in most cases. Contents of sea water in lava. Volcanic dust. Organic indications in such dust. Mechanical origin of volcanoes. Theories of Humboldt and Von Buch. Opposing views of Darwin, Lyell and Scrope. Explanation of Jorullo, in Mexico, quoted by Humboldt. Extinct volcanoes. Instances in Auvergne, (Central France) and on the Rhine, near Bonn.

PAGE
Relations of volcanoes with one another. How produced. Condition of the earth's interior as deduced from such phenomena. Connections of volcanoes with earthquakes. 293

CHAPTER XVII.

EARTHQUAKES.

Nature of vibrations of the earth called earthquakes. Earthquakes common in volcanic districts, but often felt in countries at a great distance from volcanoes. Illustration of the connection existing between volcanoes and earthquakes. Example of Stromboli—of Pasto, in Peru—in the Azores and West Indies,—in the Mississippi valley. Nature of an earthquake. Position of its source. Variety of explosions. Three kinds of earthquakes. Destruction to human life in great earthquakes. Various phenomena preceding earthquakes and serving as warnings. Noise accompanying earthquakes. Vast area over which such noises have been heard. Direction of axis of disturbance indicated during an earthquake. Distribution of earthquakes in space. Difficulty of discovering the exact point at which vibration has commenced. Matters to be considered in estimating the importance of an earthquake. Magnitude of area affected. Three classes of areas. Practical limit of a shock.
Description of the belts of earthquake action. North western area, including Iceland. Northern band, from Sweden into Russian Lapland. Southern area, from Portugal to the Azores. Band from Tunis, through Sicily, into Italy. Central and eastern French area. Rhenish system. British Islands, western France, and the Channel Islands connected by one belt. Earthquakes in the Carpathian and Balkan ranges. Earthquakes in eastern Europe and Greece, and north-eastern Africa. Line of disturbance in northern India, in central Asia and in northern Asia. South American band. Earthquake area in north-western America and in the Arctic seas, in the Antarctic circle, in Australia, and Van Diemen's Land. General conclusions concerning earthquakes. Distribution of earthquakes in time. Perrey's and Mallett's calculations on this head. Recorded earthquakes considered. Small proportion of really important earthquakes. Number of days that pass without an earthquake being felt.
Law of earthquake-distribution. Periods of intensity and intervals of repose, the usual law. Certain centuries have been marked by great results. Arrangement of earthquake areas. Distribution of earthquakes in different seasons. Case of the Scandinavian peninsula. Case of the British islands. Spanish peninsula. Other parts of Europe. North Atlantic and North America. West Indies. South America. Excess of earthquakes in winter and autumn. Periodicity of earthquakes in reference to the moon's age. Groups of smaller earthquakes. Very violent earthquakes. Distance of point of origin. 316

PART THE SIXTH.

LIFE.

CHAPTER XVIII.

THE DISTRIBUTION OF PLANTS IN THE DIFFERENT COUNTRIES OF THE EARTH.

Relation of life to the universe. Vital energy a form of force. Life an essential, not an exceptional phenomenon. Absence of materialism in this view. Selection of a plan of creation. Requirements of life. Conditions favourable to life. Life thrusts itself in everywhere. Modifications of form incident to life. Death a natural and inevitable result of life. Growth of species resembles growth of individuals. Distribution of plants and animals. The best adapted species must be those existing permanently in a district. Importance of this law of nature.

Grouping of plant life. *Cryptogamia.* Habits and distribution of these plants. Their seeds everywhere present. *Monocotyledons.* Nature of the plants thus named. *Dicotyledons,*—their nature and structure. Growth of plants. Annuals and perennials. Conditions favourable to the distribution of plants. Causes climatal. Limits of vegetation defined by climate. Advance of vegetation sometimes at the expense of animal life. Botanical regions. Humboldt's regions. Distribution in space horizontally may compare with distribution vertically. Difference of range of plants in different districts, how caused. Species of plants representative, not identical. Nature of representation in horizontal space. Transmission of species sometimes possible, but often impossible. Migration of plants limited, but may extend very widely. Examples of very wide range.

Floras of different regions. Indo-Australian Archipelago—marked distinction in floras of the western and eastern sides. Indo-Malayan region and its botanical contents. Example of Java. Flora of Hindostan plains. Contrast of the flora of the banks of the Amazons and Brazil. Flora of tropical Africa. Difference of floras of eastern and western Africa. Euphorbia tribe, a connecting link. Tropical Arabia and its flora. Floras of Africa out of the tropics. Australian floras. Special floras of Norfolk Island and New Zealand. Floras of North America. Characteristic plants of the middle States. Difference of vegetation on the eastern and western sides of the continent. Pacific coast

PAGE

flora. Islands of the Pacific. Madagascar, Bourbon, and Seychelles islands. Sandwich island group. Galapagos Archipelago. Effect of natural barriers of various kinds on floras. Floras of the temperate regions of the Old World. Variety of floras in the British Islands. Characteristics of vegetation of central Europe. Differences north and south of the mountain chain. Differences in advancing eastwards. Floras of northern Asia. The steppes. Chinese flora. Arctic vegetation.

General conclusion concerning land floras confirmed by distribution of plants in the ocean. Nature of marine plants. Dr. Hooker's provinces of marine vegetation. Wide spread of the more highly organised marine plants. Lower forms of vegetable life. Confervæ of the Red Sea and other seas. Throughout all nature the representative forms can live with each other. No new centres of creation and systems of new plants. Absence of proof of cataclysmic destruction, or sudden destruction of groups of species 333

CHAPTER XIX.

THE DISTRIBUTION OF ANIMALS ON THE EARTH.

Distribution of land animals resembles that of plants, following similar laws. Species originate at certain points, and do not naturally proceed beyond a certain distance. Illustration in the case of the horse in Europe, and of the dog in Australia. The dodo, the rat, the wolf, and the beaver, further illustrations. Introduction of man. Distribution of marine animals similar. Regions of depth established by Professor E. Forbes. Distribution of the animal kingdom. Inhabitants of the sea. Marine mammals. The seal and walrus, dugong and manatee. Marine birds. The penguin, petrel, and albatross. The pelican and cormorant. Deposits of guano by birds. Marine reptiles. Fishes not the only fit tenants of the water. Rare occasions on which fish leave the water. Examples of flying fish and creeping fish. Habits of fishes. Movements of fishes. Examples of strangely-shaped fish and fishes with singular habits. Fish adapted for human food. Herring and cod. Fish live in deep water. Crustaceans. Annelids or worms. Danger to telegraph wires. Molluscs. The cuttle fish or squid, and nautilus—their structure and habits. Other animals inhabiting shells—their beauty and habits. Phosphorescent molluscs and allied animals. The salpa. Radiated animals. Star fish of various kinds. Discovery of star fish at the bottom of the Atlantic. Sea nettles, and Medusæ or jelly fish—their use as food for the largest aquatic animals. Sea anemones and polyps. Coral animals and their structures. Foraminiferæ or the inhabitants of many-chambered shells. Sponges—their structure.

Land animals. Insects and spiders. Insects generally most abun-

PAGE

dant in the tropics. Efficacy of natural barriers. Mountain chains and rivers compared. Abundance of insects near tropical rivers. Conveyance of certain species. Limitation of some, as the *tset-zee*, to certain localities. Insects with great powers of flight. Locusts and ants migrate. Great influence of the migratory instinct. Law of nature deduced from studying the instincts of species and local faunas. Distribution of reptiles. Their peculiarities. Natural groups. Java and America extremely rich in species. Australian unlike Asiatic species. Frogs much limited. The Surinam and Brazilian toads compared. Serpents of Europe contrasted with those of North America and Australia in similar latitudes. Africa, the land of serpents. Tropical Africa and tropical America compared. Crocodiles in various warm countries. Range of crocodiles. Asia rich in lizards. Tortoises and turtles. Marine turtles. Large districts without reptiles. Birds, their great powers of locomotion. Natural groups of birds. Tropical America the richest country. Migration of birds. European characteristic birds are finches and singing birds. Asiatic gallinaceous birds also characteristic. Brazilian birds extremely brilliant in plumage. Africa rich in birds. Ostrich, secretary bird, honey birds and parrots, very common. South America also rich. Humming birds and parrots very abundant, but not easily obtained. Vultures and condors common in South America. Australian birds very singular. Australian bird fauna, and the apteryx. Extinct species.

Quadrupeds or mammals. Their wide distribution. Natural groups. Monkeys, baboons, chimpanzee, and gorilla, in central Africa. Carnivora richest in the tropics. Numerous species found in northern Asia. Mixture of species found there. Instance in the scaly ant eaters. Complete separation from the Australian types. The marsupial character of all the species. Peculiarity of Australian faunas. Africa a curious zoological province. South American and Australian quadrupeds may be compared. North America remarkable for large ruminants. General resumé. The condition of quadrupeds corresponds with that of plants. Suggestions as to how the changes have been introduced. Probable law governing such changes 354

CHAPTER XX.

DISTRIBUTION OF PLANTS AND ANIMALS IN TIME.

Old argument concerning organic remains. Origin of the name *fossil*. Identity with the indications of extinct animals. Origin of *Palæontology* as a science. Distribution of species in time a law of nature. Results that should be obtained by the study of palæontology. Prospects of future and more complete discovery of the laws of distribution. Present state of the science. As-

PAGE

sumption of specific centres. Natural provinces thus designated. Necessity of tracing back the history of provinces. Relation of various families of animals and plants in one province. Connection of races separated by impassable barriers. Example in the case of the marine faunas of the eastern and western shores of central America. Other examples in the islands of the Pacific. Distribution, in time, of the same nature. Great amount of time demanded.

Proof that the conditions of the earth and its relation to the sun have always been the same. Death has always accompanied life. No monopoly of life at any time. The species as well as the individual dies. New species introduced, but the law or method of introduction not taught. Mr. Darwin's induction on this subject. The great struggle for existence, and the check on indefinite extension of any species. All species liable to crowding out and destruction. Result of the struggle for existence. Limit of human power in modifying species. Law of natural selection as applied to species. Order arises out of this incessant struggle. Derivation of species the most simple and orderly law.

Vegetable remains found in rocks of all ages. All kinds of plants included. Cambrian vegetable fossils, marine. Land plants in silurian rocks. Remains of ferns most abundant. Club mosses, cycads and coniferæ accompany ferns. Lepidodendron, calamites and sigillariæ, the names given to the most remarkable and abundant trees. Account of the lepidodendron and sigillaria. Zamias and Cycads of somewhat less ancient date. Tertiary fossil vegetation. Difficulty of identification of fossil plants.

Animal remains. *Protozoa.* Sponges—their peculiarities of structure and distribution. *Foraminifera*—their structure, habitat, extent of fossil remains, and existence in the oldest rocks. Large rocks made up of fossils of this kind. The mud of the Atlantic made up of their skeletons. Species named, many; but real species probably few. Wide range of some species. Other fossil invertebrates. *Graptolites*—their range and modern representative. Stony corals. *Bryozoa*, and their range. Starfishes, and other *Radiata.* Pentacrinites. Distribution of radiata in time. *Articulata*, and their distribution in time. Barnacles common in the rocks of the cretaceous period. Crustaceans. *Entomostraca* widely spread from the earliest time. Large size of Old red sandstone crustaceans. Resemblance to limulus. Trilobites very common in old rocks. Structure and distribution of trilobites. Insects, not abundant in a fossil state. Examples of fossil genera. *Mollusca* very common and widely spread. Value of molluscous remains and shells in geology. The brachiopoda and their distribution now and formerly. Habits of existing species. Great resemblance of some fossil to some recent species. Aberrent forms of brachiopoda. Rhynchonella, and its representatives. Great abundance of extinct species. Other varieties of brachiopodous shells. Other bivalve shells. Large number of extinct species. Remarkable groups. Oysters, scallops, cockles, boring shells, and others. Extinct univalves. Snails. Hetero-

PAGE

poda. Cephalopoda. Various and numerous extinct forms of cephalopoda. Ammonites and belemnites—wide distribution of these univalve molluscs in certain rocks, and absence of them in older rocks. Explanation suggested by Mr. Darwin. Imperfection of the geologic record the real cause. Nature of this record.

Doubt whether fishes were associated with less complex forms of animal life in old rocks. Oldest fish remains yet described. Kinds of fish represented. Coprolites of fishes. Spines and teeth common with fragments of the skin. Difficulty of accounting for the introduction of new species. Doubt whether the negative evidence afforded by the absence of fishes is significant. Abundance of remains of sharks and rays, and rarity of other fishes' remains in old rocks. Reason why the teeth are most frequently and best preserved. Limit of teeth of true sharks. Remarkable forms of fishes. The *Pterichthys*, *Cephalaspis*, *Coccosteus*, and other characteristic fishes of the old red sandstone. Siluroid fish. Flagstones of Caithness modified by these fossils. *Megalichthys*, its peculiarities of structure. *Lepidotus*, its peculiarities. Sturgeons, sword-fish, and known forms also found fossil. Professor Owen's conclusions with regard to fossil fishes. Value of fishes to the palæontologist and geologist. This does not involve a necessary advance in all species.

Ichnology, a peculiar department of palæontology. Fossil footsteps. Indications of inanimate and animate nature in ancient times, thus designated. Nature of such indications. Mode in which impressions may have been preserved. Curious objects indicated in old rocks. *Labryinthodon* thus originally discovered. Curious structure and habits of this animal. Singular proportions of the extremities. The footprints once called *Chirotherium*. Value of these indications. Conclusion with regard to classification suggested by them.

Reptilian remains. Marine reptiles of large size. *Ichthyosaurus*. Minute details of the animal made out. Combination of fish and reptilian characters in the *Placodus*. Comparison with Australian lizards. Structure of the *Plesiosaurus*, another marine saurian. Curious form of skeleton. The *Pliosaurus* less abnormal in some respects. Curious saurian, whose remains were found in South Africa (*Dicynodon*). The *Rhynchosaurus*, found in England. The *Pterodactyl*, a very remarkable reptile, adapted for long flight. The *Megalosaurus*, or great carnivorous reptile. The *Iguanodon*, a herbivorous genus. Crocodiles and crocodilean reptiles. Lizards of large proportions in the chalk. Serpents, tortoises and turtles. Professor Owen's conclusions concerning reptiles.

Mammals (quadrupeds) and birds now the ruling animals. Birds known by their footsteps, which are peculiar. Dr. Green's discovery of bird's footsteps in America. No other proof needed of the existence of the bird. Small value of negative evidence illustrated by this example. Modern discoveries of bird's remains. The *dinornis* of New Zealand. Comparison with the apteryx. Birds' eggs from Madagascar. Dodo and solitaire in

PAGE

Mauritius. Peculiarities of the dodo. Rarity of bird's remains. Occurrence of remains of quadrupeds. Difficulty of determination from the evidence generally obtained. Value of certain parts of the bony frame-work. Extreme value of teeth when they remain. Oldest known forms of quadrupedal life, marsupial and very small. Other marsupial quadrupeds of small size made known in the oolites. Value of the evidence thus afforded. The tertiary rocks richest in mammalian remains. Earliest forms in tertiary period. Tapir-like animals. Cuvier's discoveries of extinct pachyderms and ruminants in the Paris Basin deposits. Other animals since discovered. Carnivora. Edentates. Whales. Phosphatic beds composed of bones and other organic remains. Change of quadrupeds in newer tertiaries. Remains of elephants associated with human productions. Remains of quadrumanous animals. Other gigantic quadrupeds now extinct.

Deductions from the facts of palæontology. Inquiry as to how far species are fixed and definite. Nature of specific characters. Mr. Darwin's argument alluded to. Law of nature in respect to the continuance of species. Modification of species leading to extinction. General result of the investigations of palæontology as stated by Professor Owen 379

CHAPTER XXI.

EFFECTS OF HUMAN AGENCY ON INANIMATE NATURE.

Influence of man greater than other animals. Result of burning prairies and forests. Vast extent of a single fire under certain circumstances. Effect generally greatest in civilised countries. Effect in deteriorating climate. Land originally thickly wooded in temperate climates. Naked rocks and mountain sides once covered with forest. Examples in the Ionian Islands. Influence of certain animals in checking the increase of forest. Difficulty of measuring the result. Statistical statement of the cultivated lands in North America. Quantity of food grown. Different ways in which human influence is exerted. Destruction of certain animals, as birds and insects,—result of this not seen immediately. Electric influence exercised by forests. Influence on the state of the atmosphere. On the temperature. On certain soils more than others. On more rather than on less exposed soils. Result of clearing the Apennines on the valley of the Po. Increased winds on account of this change. Result of removing the pine woods of Ravenna, and of allowing the trees afterwards to grow. The valleys of Bergamo affected by the disforesting of the adjacent country. Similar results in Belgium, in France, and in Canada. Change of climate probable in the north temperate zone. Changes in the rivers. Probable influence of forests on rain. Dryness of many parts of the con-

PAGE

tinent caused by the removal of wood. Restoring forest has produced wetter seasons in Egypt and elsewhere. Forests affect the supply of water to springs. Illustration of change in the valley of Aragua. Consequently of change very distant. Actual quantity of woodland in France in 1750 and 1860.

Other effects of human influence. Drainage of lakes and fens. Examples in England—in Holland. New banks and dykes formed. Growth of vegetation strengthening such new banks. Mode of forming an embankment. Drainage of lake of Haarlem. How and when effected. Drainage of lakes in ancient times in Italy—in Chili—and in Switzerland. Drainage affects the evaporation, and thus the temperature. Irrigation accompanying drainage. Great antiquity of irrigation. Examples in Palestine, Spain, and Turkey. Result on the water courses in Lombardy. Embankments and production of artificial channels affecting the transmission of water. Examples of deviating streams from their natural courses. Val di Chiana.

Deposits of sand. Advance of sand on the shores of Gascony and in the great Sahara. Available means in vegetation for checking the advance. Conditions of the sand while advancing. Production of hills artificially or naturally. Dunes or sand hills on the shores of the Bay of Biscay. Terrible result of neglect of dunes. Mode of their destruction. How sand hills can be formed or caused to form. Use of the *Arundo arenaria* or *marram*. Protection of dunes by planting.

Effect of engineering and other operations. Cutting across isthmuses. Deposits left to harden and collect. Piercing the roof of a cavern. Heaps of potsherds and rubbish. Mining for coal or metals. Springs thus affected 421

PART THE FIRST.

INTRODUCTION.

PHYSICAL GEOGRAPHY.

CHAPTER I.

THE EARTH AS A PLANET.

Around the sun as a centre there revolve a vast but unknown multitude of material bodies, all governed by the same general laws, and apparently possessing many mutual relations. These, together form the solar system, or that portion of the universe with which the inhabitants of the earth have traceable relations. A few of these bodies are the six planets known from the earliest times. Among their number is included the earth on which we live. Two other planets, much more distant from the sun than those recognised in ancient times, but comparable with them in all essential points were discovered, one in the last and the other in the present century. More than seventy celestial bodies, much smaller in dimensions, and very exceptional in their movements, have been made out within the present century, most of them having been discovered since the year 1845. A still less orderly and countless multitude of material fragments appear to revolve round the sun, nearly at the same distance as the earth, but with double its rapidity. These cross the path of the earth twice a year, in August and November, and such of the fragments as then pass through the atmosphere become hot and luminous by the friction, and are recognised as shooting stars. Who can tell with what other similar groups space is peopled, falling in the way of other planets, or roaming uninterruptedly in the enormous spaces between the sun and the more distant planets? These spaces are occasionally crossed by comets, of which some reach far beyond the furthest known extension of our system, and others are confined within narrow limits. It is not unlikely that matter in some form—an ether, or exceedingly thin vapour—extends everywhere, and forms the connecting link, conveying and communicating light and heat, and conducting to suns and stars from distant space the fuel that keeps the material universe in equilibrium. With few exceptions the various bodies composing our planetary system all move within one very thin slice of a sphere, whose centre is the sun, and radius the longer axis of the orbit of the outermost comet. Within that great sphere, of which the sun is the centre, and which thus includes the extreme wandering of the most outlying of its dependencies—a sphere of limited dimensions, and of which figures may express the dimensions, but of which no stretch of the imagination can conceive the real magnitude—all that exists would seem to be in incessant motion. Each atom that helps to make up the whole has a special motion with reference to the particular form of matter of which it is a part, and each mass also, whether a mere thin vapour or a dense solid, has another, and quite independent motion, co-existent with it. Every group of such masses has again other motions, and all are governed by laws so wise, so far-seeing, so perfect, that the combined motions produce only definite, regulated and fore-ordained changes, and conduce to the well being of the whole system. The most intelligent and the widest idea of creative power is certainly that which assumes the most perfect mutual adaptation of every member of the whole system.

Heat, light, electricity and magnetism, are names given for various expressions, conditions, or recognisable attributes of matter. They are the expressions we use to enable us to speak conveniently of certain grand and definite results of various forms of force exhibited in motions going on through space. Wherever motion takes place there are results whose special nature and modes of presentment are determined by circumstances, but whenever and wherever motion occurs it is merely an expression of heat, light, or electricity, and is convertible into one or other of them. This is one of the axioms of modern physical science. That motion is not limited to the masses of bodies, but is actively taking place always, and under all circumstances, within all masses, whether solid, liquid or gaseous, and often without approaching the surface, is the first and greatest lesson that the student of physical geography and geology must learn.

Most of the heavenly bodies—the earth and moon amongst the number—are nearly spherical in form, but owing to the action of certain laws that govern matter the spheres are flattened so that a bulge is presented at the equator and a compression at the poles. The earth, like the other planets, revolves round an imaginary axis, and revolves also round the sun. The poles are the points on the surface through which such an axis would pass if it really existed. The equator is the circumference of the earth equidistant from these poles.

The earth is the third in distance from the sun and the fifth in magnitude of the larger planetary bodies of our system. Like others of the larger planets, it has a satellite or follower, a smaller spherical body, revolving round it with great regularity, and revolving with it round the sun. This satellite we call the "moon." It influences the earth, and is influenced by the earth. Each affects the other in proportion to the quantity of matter each contains.

The magnitude of the earth, as estimated from careful measurements, may be thus stated. The mean diameter may be taken as about 7,926 British statute miles, or, in other words, the distance of the centre from any point of the surface would be 3,963 miles, if the earth were a regular and perfect sphere. As, however, the equator bulges, and the poles are flattened, the distance of the poles from the centre is only about 3,956¼ miles, while the distance of a point on the equator from the centre is as much as 3,969½ miles. The difference of diameters (called the *compression*) has been calculated with very great care. It is 26½ miles, a distance nearly double that which exists between the extreme depths of the ocean and the loftiest mountain peak. The earth's surface contains nearly 197,000,000 square statute miles. Its solid content is 256,000 millions of cubic miles. The form of the earth is not, however, perfectly regular, and thus a line drawn from the centre to the surface in the Pacific Ocean is nearly a mile longer, and a line drawn at right angles to this a mile shorter than the average.

The various calculations made agree within a small fraction of the whole, and the figures given above are the latest results attainable.

The distance of the moon from the earth is about 239,000 miles, or thirty times the diameter of the earth. The mass of the moon, which is only about one-eightieth part of the mass of the earth, is still sufficient at that distance to produce disturbances of considerable magnitude on the surface of our planet.

This is chiefly recognised in reference to the great body of water that covers so large a part of the surface. It produces there the oceanic tides, and in the atmosphere there are similar movements effected, both at fixed intervals, and irregularly.

The mean distance of the earth from the sun is 94,800,000 miles; but the distance is not at all times the same, owing to the fact that the orbit is elliptical, and not circular. Moreover, the excentricity of the orbit, or difference between the ideal circle and real ellipse, varies from year to year through a very long cycle, and thus are introduced causes of change which may be of great importance. Thus, when the excentricity is greatest, the greatest distance from the sun to the earth may amount to 102,256,873 miles, and its nearest distance will then be only 87,503,039 miles, showing the very considerable difference of 14,753,834 miles, or more than one-seventh of the longer semi-diameter. This is a very important fact, for as the amount of heat received from the sun varies as the square of the distance, it follows that the quantity of heat received in the former position, compared with that in the latter, will be as 19 to 26.

So slow, however, is the change in excentricity, that although it is now diminishing, and has been so for a long time, it will continue to do so for nearly twenty-four thousand years without being reduced to a minimum.

The actual distance of the sun from the earth changes every day, and owing to certain changes that take place in its movements, also occupying a long cycle, (extending, however, over 25,686 years only), it happens that, occasionally, (as at present) the earth is nearer to the sun in the northern hemisphere during winter than during summer. At other parts of that cycle the case is different. If, when the excentricity is greatest, the earth should happen to be in such a part of this latter cycle that the case is reversed (the earth being nearest in summer) the land of the northern hemisphere would be warmed only to the very minimum extent in winter, and heated to a maximum in summer. The difference would then equal one-fifth of the whole. There would then be far more extreme climates on the earth than there are now. Causes of change of climate are thus introduced, which may account for those singular differences that an examination of the earth's crust has shown to have taken place in former times. The total quantity of heat received from the sun in a year would, however, change exceedingly little.

The present excentricity of the earth's orbit is such that during winter, when nearest the sun, the distance is 93,286,707 miles, and in summer, when farthest from it, is 96,331,707. Between nine and ten thousand years ago the earth was nearest the sun in summer and furthest in winter, and the excentricity was greater than it is now. This difference was certainly sufficient to produce a far more excessive climate, that is, a climate much hotter in summer and cooler in winter. As much as 210,000 years ago the difference was nearly a maximum in every way. Then, perhaps, was one of the glacial periods of geologists, for then the winter was nearly a month longer than summer, as well as much colder than it is now.

The earth revolves round the sun (nearly 600 millions of miles) in a year, consisting of 365 days or revolutions of the earth, and nearly one-fourth part of a day more. The exact length of the 'civil' year is 365 days, 5 hours, 48m., 47$\frac{1}{2}$s. The day is the period of rotation of the earth round its imaginary axis. This ideal axis is not always the same, and it is inclined at a certain angle to the plane passing through the centres of the sun and earth, and in which, therefore, the earth revolves round the sun. Thus it arises that the length of day and night is only equal at the equator all the year round, but that at each place there are two occasions in the year when the length of day and night is the same. These times are called *equinoxes*, (equal nights). As the light, so also heat, is very irregularly distributed over the earth.

The sun is enormously large in comparison, not only with the earth, but with all the bodies of our system. Its diameter is 848,077 miles. It has, therefore, a diameter more than a hundred times greater than that of the earth. In bulk it is equivalent to nearly a million and a quarter such globes as ours. But a large part is probably in a state of gas, and the matter of the sun is certainly very much less dense than that of the earth. Thus, in actual quantity of matter, it is only about 320,000 times greater than the earth. It is, however, 1,800 times greater in actual quantity of matter than all the planetary bodies, satellites and comets forming the system of bodies of which it is the centre, and this vastness of its mass renders it a fit and steady centre, round which all its subsidiary masses of matter of all dimensions continue to circulate. The earth is affected by the moon, the sun and the other bodies of the solar system, being attracted by them and attracting them. Thus is produced a certain amount of irregularity in its motions in space, but as these are periodical and do not tend to increase beyond certain limits, there is no element of destruction. The equilibrium of the solar system, so far as regards these causes of disturbance, is believed to be complete, and is certainly complete compared with any period of time we can imagine.

It is believed, from observations made on the stars, that the whole of our solar system forms one group of matter, having its own proper motion in space and moving according to some unknown law in some one definite direction. In this way it is thought that the solar system is connected with some special group or groups of stars, and forms, perhaps, itself but one star in the mighty host of heaven.

As, on the one hand, physical geography requires us to connect the earth with the other bodies of the existing universe, so, on the other, it is necessary to consider it in its past history. For the former purpose we are bound to commence our treatment of the subject with astronomy, and for the latter we must now allude to geology.

Of the interior of the earth, at great distance below the immediate surface, we know very little, and that little partly by inference partly by studying the sections of the surface that are accessible. Mines and wells reach but a very short distance and could teach us little were it not for the mode of arrangement of strata. The study of the rocks and of their stratification and disturbances, with a view to determine the earth's history, is the science of geology. The rocks exhibit successive changes that carry us back through a very long period of time, but they fail to afford any satisfactory evidences of the state of things at the beginning. All they do in this respect is to show that the conditions of existence have not changed in any essential point.

The earth's crust is made up of a long succession of deposits, originally of mud and stone, and each containing relics of an ancient world. Most of these are greatly changed from the state in which they were accumulated. Throughout the whole series everything seems to point to an exceedingly long period occupied in the formation of each deposit, and very long intervals during which deposits have been withheld.

But besides these accumulations of stratified and mechanically formed rocks are others, such as granite, which were once thought to represent the material of the interior of the earth There is no reason to suppose that any granite with which we are cognisant has been formed even at so great a depth as twenty miles, a distance so small compared with the earth's diameter that it fails to have any value in guiding us to a knowledge of the more distant material of the real interior. At that greatest depth it seems clear that the ordinary surface conditions, acting upon ordinary surface materials, might and would have produced the rocks we find. They may, therefore, be nothing more than altered conditions of such rocks as are still formed and deposited in our seas. By slow degrees covered up, and afterwards depressed, the sand and mud of a sea bottom are soon brought under the combined influences of heat and pressure, and the currents of electricity and earth magnetism, acting through the agency of water, have effected great chemical and mechanical change. Once altered the rocks have been again elevated and exposed to mechanical action at the surface.

That within the earth there is at a moderate depth an equable temperature throughout the year, and, as we descend, a somewhat irregularly increased permanent temperature, is a fact of observation. This temperature, if it continues to increase regularly according to the same law (1° F. for every 60 feet), would at very moderate depths be sufficient to fuse rocks of any kind, even notwithstanding the increased pressure of the surface. It has been proved by experiment that water not only penetrates and circulates through rocks at great depths, but that under the extreme pressure at those depths the rock becomes more and not less permeable to water, and is likely to be more easily acted on by chemical causes of change.

The density of ordinary rocks at the surface of the earth is very much smaller than the mean density of the whole mass. The latter is about five and a half times greater than water, most of the surface rocks being only about two and a half times as heavy as water. It is clear, therefore, that the material of the interior must be uniformly more dense, or else unlike that which we are in the habit of seeing at the surface, unless, indeed, the temperature diminishes instead of increasing, in spite of the increased pressure. It has been calculated by Professor W. Thomson, of Glasgow, and Mr. W. Hopkins, of Cambridge, that the crust of the earth must consist on the whole, and to an enormous depth, of some kind or condition of solid material more rigid than steel. If it were not so, the height of the tides and the amounts of precession and nutation would be smaller than they are found experimentally to be. The rigidity of the uppermost crust of the earth, as known to us by observation, is, however, less than that of glass, so that to produce an average agreeing with calculation, the rigidity must increase towards the interior. This conclusion is altogether inconsistent with the hypothesis that the earth is a mass of matter still in a state of fusion, inclosed within a hard shell, which, to be affected by earthquake and volcanic action, must be less than 100 miles thick. It agrees, however, with other calculations, also from astronomical data, tending to prove that the crust cannot under any circumstances be less than 800 miles thick. It seems most likely that at least half the distance from the surface to the centre must be solid and rigid, to enable our planet to preserve its figure, and allow the tides of the ocean and the movements of the earth to remain as they are.*

The material elements of the earth are known only by those presented to us at the surface, and it is a singular example of the difficulty of determining these completely and with accuracy that within the last few years more than one has been discovered during the progress of experiments and observations concerning the nature of light and the probable composition of the sun's atmosphere. The real proportions of the various supposed elements in the interior and the relative importance of each may be quite different from anything we can determine at the surface, and in the following remarks it will be understood that reference is only made to positive knowledge.

---

* A notion has been put forward recently by Mr. Evans, and rather supported by Sir H. James, to the effect that the axis of the earth is liable to be shifted by the change of position of matter on the surface. This idea has been successfully combated by the Astronomer Royal, and is not supported by geological investigations.

In a technical sense elements are material substances that have not hitherto been obtained in a state admitting of decomposition into two or more other substances. Whether they are really simple in the ordinary sense of the word, or whether they are compounds of some one or more ultimate forms of matter, permanent under the action of all known causes of change, need not here be discussed. It seems certain that of the supposed elements not a few are common to the sun and earth in the state in which we know them, and it is not unreasonable to assume that the other planets and satellites are similarly constituted. The results of recent observations would even tend to show that the fixed stars, vast as their distance is and completely as their stellar systems seem to be separated from our solar system, are yet possessed of material elements such as those that exist in the earth. This conclusion has been drawn from experiments recently conducted in reference to the dark lines in the image produced on separating the rays of a pencil of solar, stellar or other light. It is a conclusion of the deepest interest, and conducting to important results in the pursuit of physical geography, connecting as it does the various material centres of the universe, and suggesting their common origin.

Matter is presented on the earth in three forms—solid, liquid and gaseous—due to the presence of heat, and to the different mode in which different combinations of material atoms are affected by heat. Some of the elements, and some combinations of certain elements, are capable of existing in either form at ordinary temperatures. Other elements and other combinations exist only in one or two of the three states, though perhaps capable of alteration by increments or decrements of heat under conditions hitherto undiscovered. Thus oxygen, hydrogen, nitrogen, chlorine and fluorine, when pure, are gaseous, and have never been condensed into fluids. Bromine and mercury are fluid, but easily rendered either solid or gaseous. The other known elements (between fifty and sixty in number), are solid, but may be melted and vapourised by heat. Of combinations of two elements, some are fluid, as water (a combination of oxygen and hydrogen), others gaseous, as ammonia (nitrogen and hydrogen) or carbonic acid (carbon and oxygen), others solid, as iron pyrites (iron and sulphur). It is possible that all the elements may exist in a pure state in extremely minute division, and in a very small proportion, both in water and air. If this be the case, they must assume the mechanical condition of the substance into which they are absorbed or with which they mix.

Of the elements existing in the solid form at the earth's surface at ordinary temperatures, there are some which liquefy on exposure to heat before becoming gaseous, and some that pass into the state of vapour immediately, without first liquefying, when the temperature is increased. The metals are examples of the former, carbon of the latter condition. As also the temperature at the earth's surface varies greatly in different parts and at different seasons, there is one element (mercury) and one important compound (water) that are solid or fluid in different parts of the earth at the same time. Exposed to the extreme cold near the poles mercury is solid, and may be hammered like lead. Exposed to the ordinary cold of winter in the temperate zones, or at high elevations even in the tropics, water becomes ice. There are many familiar examples of natural substances where the mechanical state changes within very moderate limits of temperature.

Of the elements, as determined by the chemist, a few are sufficiently abundant and common near the earth's surface to be familiarly known in their simple state. Of these CARBON, PHOSPHORUS and SULPHUR, are non-metallic. GOLD, SILVER, COPPER, BISMUTH, ARSENIC, ANTIMONY and PLATINUM, exist in their natural state as metals, and are sometimes so obtained from the earth. IRON, LEAD, ZINC, TIN and NICKEL, though used abundantly in the metallic state, and remaining unchanged when once reduced, are very rarely, or never found in a native state. MANGANESE, CHROMIUM, COBALT, ALUMINIUM, and a few others less important may also be named as capable of remaining metallic without change, but never found so. CALCIUM, POTASSIUM, SODIUM, and some others, are seldom seen, and their influence is hardly recognised as metals, but in a combined state as earths they are infinitely abundant, and of the greatest importance in the construction of rocks. With regard to some few recently discovered by means of spectrum observations, they may be present in the interior of the earth, and they seem to be common to the earth and the solar atmosphere: but we know of no use to which they have been put by nature, and they have not yet been applied to any practical purpose by human ingenuity.

Let us return for a moment to the consideration of metals whose combinations, on account of their extreme abundance near the earth's surface, and the part they play in the formation of common rocks, must be regarded as more influential than most of the elements. POTASSIUM and SODIUM are obtained as metals by difficult chemical processes, but in other forms they are almost universal. Combined with chlorine, under the form of common salt, sodium is an important ingredient in the waters of the ocean. MAGNESIUM, hardly known as a metal, is also present in the sea. It is of the greatest importance in certain rocks, though the mode in which it obtained access to them is quite unknown. CALCIUM and ALUMINIUM, the metallic bases of limestone and clay, and SILICON or SILICIUM, the element which yields sand, and all varieties of silica and siliceous rock, must be regarded as more important and influential on the earth than any other elements. Except ALUMINIUM, which has lately been produced in large quantities at a moderate expense, and SODIUM, manufactured for certain special purposes on a large scale, none of them are brought into the metallic state, except as chemical curiosities, nor have they any known uses as metals. It is not till combined with oxygen that silicon becomes flint, or aluminium the basis of clay, and both oxygen and carbon must mix with calcium before it becomes limestone (carbonate of lime), and oxygen and silica with alumina before clay (silicate of alumina) is obtained.

The natural combinations of elements are few, compared with the number there must have been, if all the elements entered into mutual combinations with equal facility. There is an important limitation in this respect. In nature the total number of elements and substances that may conveniently be called proximate elements, and that enter largely into the composition of the earth's surface, is extremely small, and easily learnt. It may be useful to name and describe briefly the materials we are most likely to meet with, and that appear to have had most influence in the formation of the earth.

Beyond all doubt the substance that is most important and most essential on the earth's surface is OXYGEN GAS. This substance forms one-fourth part by weight of the whole atmosphere, and nearly nine-tenths by weight of the whole of the water on the earth. It occurs in about a hundred and forty combinations, independent of life or organisation, and in a large number of organic compounds. It may be estimated to constitute at least one-third part by weight of the solid mass of the earth which, so far as we know it, is composed chiefly of metallic oxides and oxygen salts. It is obtained without difficulty in a pure form, although it can hardly be said to exist in nature in a simple state, its mixture with nitrogen in the atmosphere masking many of its properties. Oxygen, though so readily forming solid compounds, has never been liquefied, much less solidified. It combines in various proportions, its simplest combinations generally assuming the form of *acids*. These, again, combine separately, with various elements and compounds, producing the group of *salts*. The earths, for the most part, are double compounds, oxygen being present in both. Thus carbon combines with oxygen to produce carbonic acid, and calcium with oxygen to produce quick-lime. Carbonate of lime, or limestone, is a compound of carbonic acid and lime. So aluminium and oxygen form alumina, silicon with oxygen silica, and silica with alumina form silicate of alumina, the basis of clay. Oxygen combines with most of the metals very readily, and forms important compounds. Thus oxide of iron is everywhere present, both in organic and inorganic nature, while for metallic iron man is indebted to his own exertions and ingenuity. Manganese is almost as common in the state of oxide as iron, but the metal is not used in the arts, and can hardly exist on the earth owing to the extreme readiness with which it decomposes moist air, and is converted into an oxide.

The relative abundance of hydrogen in the earth is not so great as that of oxygen, but the supply is certainly very considerable. Not only does it enter into the composition of all waters, but it is evolved from the earth in volcanic districts, and is present in coal. And it must be remembered that water is not confined to the rivers, lakes and ocean. It exists in great abundance in every part of the earth and air. All rocks contain it, and it courses through all crevices and veins. Owing to the circulation of water by rain there is a constant accumulation on the surface, and rocks are kept permanently wet by the water that enters into and passes through them. A very appreciable per-centage of the weight of every rock in its natural state consists of water.

NITROGEN constitutes three fourths of the atmosphere, and is present in many rocks, of which it may be said to form an essential part. It exists in coal, as is exhibited by the ammoniacal products obtained from the distillation of that mineral.

CHLORINE is widely disseminated, being an ingredient of common salt, which is, in chemical language, *chloride of sodium*. It is, therefore, present in salt water, and in the great masses of rock salt so abundant in some countries. PHOSPHORUS is important as entering into the structure of bone. It is much more widely disseminated than is generally supposed, and *phosphate of lime* is a frequent mineral. FLUORINE is an ingredient in a large class of minerals. It enters into the composition of granite, gneiss, greenstone, and other metamorphic rocks. LITHIUM occasionally replaces it.

Of the solid bases, SILICIUM is that which is most widely distributed. In all the old rocks, and in all metamorphic and igneous rocks it is present, almost always to the extent of 45 per cent., and usually to between 50 and 70 per cent. In some it consists of from 70 to 95 per cent. of the whole, and the greater part of whole series of rocks is composed of silica. It is present in most limestones, and even in chalk silica sometimes forms from one-fourth to one-third of the mass.

ALUMINIUM comes next to silica in order of importance. It is an essential ingredient (with silica) in all clays. Limestones, also, are rarely without it. It forms the essential mineral base of felspar, and of all those numerous volcanic rocks of which lava and basalt or greenstone (the lavas of ancient times) are the representatives. POTASSIUM and SODIUM follow next in order, if we regard universality of distribution, and CALCIUM, if quantity regulates the order. MAGNESIUM, also, is very widely distributed, being present in large classes of rocks, and sometimes very abundantly. It is eminently characteristic of whole classes of rocks.

Of the metals which form an essential part of rocks, iron and manganese are the most important. It has been calculated that in addition to those admixtures of iron and oxygen to which the name of 'iron ores' properly belongs, more than 5 per cent. of the lower stratified rocks consists of iron, and it is probable that the per-centage is still larger in the upper and newer rocks. Manganese is almost as widely distributed, but is much less in quantity. The other metals are chiefly met with in veins or crevices in rocks. Some are widely spread, but in small quantity; others are only present in certain localities, and are there tolerably abundant.

The following are the elements and combinations which chiefly enter into the composition of rocks, or which are chiefly important to man. They are grouped, for the most part, in the order in which they are described in chemical works.

I.—Elements.

1.—*Gases.* Oxygen, hydrogen, nitrogen, chlorine.

2.—*Non-metallic solids.* Silicon, carbon, sulphur, phosphorus, iodine.

3.—*Metallic bases of earths and alkalies.* Aluminium, potassium, sodium, magnesium, calcium.

4.—*Metals.* Iron, manganese, gold, titanium, arsenic, copper, silver, lead, zinc, iron, cobalt, nickel, chromium.

II.—Binary Combinations.

Oxygen and hydrogen (*water*). Hydrogen and nitrogen (*ammonia*). Nitrogen and oxygen (*nitrous acid*). Carbon and oxygen (*carbonic acid*). Silicon and oxygen (*silica*). Sulphur and oxygen (*sulphurous acid*). Potassium and oxygen (*potash*). Sodium and oxygen (*soda*). Chlorine and sodium (*common salt*). Calcium and oxygen (*lime*). Magnesium and oxygen (*magnesia*). Aluminium and oxygen (*alumina*) Antimony and sulphur (*grey antimony*). Arsenic and sulphur (*realgar* and *orpiment*). Copper and oxygen (*black* and *red copper ores*). Copper and sulphur (*copper pyrites*). Iron and oxygen (*magnetic iron ore*, *specular iron ore*, *hæmatite*, *&c.*). Iron and sulphur (*iron pyrites*). Lead and sulphur (*galena*). Manganese and oxygen (*wad*). Mercury and sulphur (*cinnabar*). Silver and sulphur (*vitreous silver* or *silver-glance*). Tin and oxygen (*tin stone*). Zinc and sulphur (*blende*).

The compounds of three elements are more numerous, and it would swell the list too much merely to name them. Water forms part of most substances without changing them. Carbonic acid, sulphuric and nitric acids, (the two latter being sulphurous and nitrous acids combined with water) combine further with lime, soda, potash, magnesia, alumina, and many of the metals, producing limestone of all kinds, salts of various kinds, and many well-known earths, minerals and metalliferous ores. Silica, (or oxide of silicon) behaving as an acid, combines with many compound substances as bases. The most important, because the best known, and the most widely spread, is silicate of alumina or clay, already alluded to. More complicated combinations are exemplified in alum (a double silicate of alumina and potash), many varieties of felspar and mica that help to form granite, and many minerals of various kinds contained in rocks.

The combinations of elements take place in nature in certain definite proportions; and it has been found that these are more distinct as the affinity between the combining substances is stronger. Mixture is very different from combination, and involves no change in the condition of the elements. Combination is a permanent condition, except with a stronger affinity. Mixtures are generally loose and accidental. But some mixtures, as that of oxygen and nitrogen, forming atmospheric air, are of the greatest importance in nature. So, also, are some of the mixtures of metals or alloys. So, again, the mixture of a certain definite quantity of water with various compounds seems absolutely essential to their existence in the solid state. It is called their water of solidification.

It is not possible, indeed, to exaggerate the importance of water in carrying on the great operations of nature. And this is the case, although there is no reason to suppose that it acts chemically, or combines with them in the strict and technical sense of the expression. The mere admixture with water is sometimes limited to certain proportions, dependent on temperature. Combinations, also, take place most favourably under certain conditions of temperature and pressure, and thus these two modes of association of elements, apparently very distinct, have certain relations with each other. There is also a kind of selection, or *elective affinity*, according to which the phenomena of decomposition of existing things, and recomposition of their elements into different minerals, are constantly taking place in nature. In this way are produced those changes of rocks in which a number of elements and combinations of various kinds are brought into contact. This is often done in the presence, and by the aid of water, without which the conditions would be unfavourable for the exercise of the affinities. A due notice of these relations of the physical forces, however, is too large and important a subject, and its bearing on physical geography too intimate to be fitly discussed in a few paragraphs at the end of a chapter.

With the earth as a planet physical geography has not much to do, and as we can never know with precision the condition of the interior, we must be content to learn all we may of the surface. When we speak of the surface of the earth, however, we necessarily include not only the land, with all its inequalities of level, of material, and of covering, whether animal, vegetable, or mineral, but also the water and air that rest upon it, and the rocks beneath the surface. If we were to regard as the surface the outer limits of our planet, using the expression in an astronomical and strict sense, we must not stop here. We should, indeed, be obliged to wander away to the extreme boundary of the atmosphere of mixed gases. But this would be a limit utterly useless to the geographer, even if it were possible to attain. The human interest of the earth, if not confined to the districts easily accessible to man, is necessarily most direct and strongest in reference to the part inhabited by sentient and intelligent beings. So, again, we must not confine ourselves to the limit of the solid surface, for we know nothing, or at least very little, of the ocean floor. We are reduced to the limit so familiar to all, namely, the general surface of contact between the atmosphere and the land or water, this surface having a visible and tangible limit, and including only so much of the rocks beneath, and the air above, as comes within observation. We may regard the earth as a solid globe, therefore, for the purposes of this investigation. Of this globe the inequalities are partly concealed by water, and the whole is covered by a thin transparent gaseous veil, definite in its composition, and easily examined and understood, being in close contact with earth and sea. Each of the three divisions of land, water and air, will demand separate and careful consideration, and in fact the study of the phenomena of each is a distinct department of science. Fully to comprehend the solid crust, the water, and the air, which are all we have to deal with in physical geography, we must, however, know something of the earth's interior, and of the history of its construction, as taught by its structure. A description of the earth's surface must thus commence with some brief account of its history. Geology, so far as this, is a part of physical geography; and it is also, to this extent, though not otherwise, an elementary and introductory part. We cannot recognise and understand the facts that are observed at the earth's surface without knowing something of the history of the surface and the rocks of which it is made up.

But if it is necessary to know something of the matter of which the earth's surface is composed, it is certainly not less so that we should be acquainted with what is known concerning the physical forces and their mode of action. Much has lately been added to the sum of human knowledge by investigations carried on in reference to these forces. It is not needful to enter into detail on the subject, but the mode in which forces are represented by motion, each being resolvable into the other, is too important to be passed by without special reference. We must thus postpone our account of those details that belong to physical geography till the reader has become prepared to understand them in their bearing on each other, and on the earth's history.

CHAPTER II.

PHYSICAL FORCES.

We have seen in the last chapter that the whole planetary system to which our earth belongs is acted on by certain forces, tending to produce motion, and it has been stated that these forces bear various names. All masses of matter or collections of material particles are subject to mutual attraction, in proportion to their quantity of matter; and two bodies, each containing a definite quantity of matter and placed at a distance, attract each other, or tend to come in contact, with a force that varies in proportion to their mass, and inversely as the square of the distance between them. This is the force of *gravitation*. By it the planets, their satellites, and the sun are mutually attracted. When, however, under certain circumstances, the particles of matter are near together, they sometimes (not always) tend to combine into one solid or fluid mass. The force thus acting is recognised as the force of *cohesion*. It is exhibited in the largest degree in compact hard solids, and in the smallest degree in fluids. Mere contact, under ordinary circumstances of temperature, is not enough to bring this force into play, but the result when two flat surfaces of polished glass are pressed together with force, or when two pieces of metal are melted together, will illustrate its nature.

The particles of matter, however, are never really in contact, for they are always capable of motion among themselves, and there are always intervals between them, admitting free motion of the particles among each other, and even of the passage of particles of other matter between the atoms or molecules of the most solid. It is a fact too familiar to need more than a bare mention that electrical, magnetic and galvanic currents, whatever these may be, pass freely through and among the particles of solids, fluids, and gases, in some cases modifying them, in others not seeming to produce any change. The various forces that may be understood as combined under the name *electricity* are known to be incessantly at work, producing and tending to produce change; and whether they act as independent material substances, or by setting in motion an ether between the particles of the solid, or by moving the particles of the solid among themselves, the same general conclusion must be admitted.

Besides the forces already referred to, changes are excited in the internal composition of many substances, and modification of structure is effected by what is called *chemical action*. The decomposition that takes place when certain substances are brought into contact at certain temperatures, and the recombination of elements, which is common and familiar in the most ordinary operations of nature and art, are examples of the existence of, and power exerted by, this force.

Vital energy is another of the great forces of nature. Not less distinct from the forces enumerated above than they are from each other, but hardly more so, we cannot, in the present state of science, regard life as other than a mechanical result of the continued action of these forces. The exact mode in which it agrees with, and differs from, other forces is not yet clear, but neither are the precise relations of these to each other. That life, however, is a result of the action of chemical, electrical, and mechanical forms of force, all modern discoveries in physical science render almost certain. The mode in which the forces act, and their mutual relations, have not yet been exemplified, either by experiment or by the study of nature.

To understand the mode of action of some one of the various forces and kinds of force that affect matter, is a great step towards a knowledge of general physics, and it is a step especially useful in the study of physical geography. Heat is that one with which all persons are most familiar, and a few illustrations of the way in which heat is convertible into other forces, replaces them, and produces identical results on matter, cannot fail to be useful and interesting, and will form a fit introduction to the present state of physical science.

Every kind and variety of motion produces heat, and every variety of motion produced by heat may be resolved into expansion and contraction, or the production of a greater or smaller interval between the component particles of the substance affected. So, also, every motion produces heat. Mercury poured from one basin into another, water falling in a cataract, the grinding of a glacier as it creeps down a valley in the Alps, the dashing of the waves of the sea during a storm, are all sources of heat. Friction, or rather the overcoming of friction, produces heat. The heating of the axles of a railway carriage is the result of friction and the interruption of smooth motion, and in so far it is a waste of power or force. A train is stopped by the conversion of motion into heat. Force is never lost, either by any change of direction or any alteration of intensity of action, it is merely converted, and the ordinary conversion is otherwise expressed when we say that interrupted motion produces heat, and that heat produces motion. Aerolites passing through the air are not only so intensely heated by friction that their advancing surface is melted, but in many cases the materials are probably dissipated. In this way the earth is generally spared the result of meeting foreign bodies moving with the velocity of planets, because these bodies are checked by friction with our atmosphere. If, however, an aerolite reaches the earth it is at once buried to considerable depth in the soil and lost sight of, always with the same result and following the same law that motion and heat are convertible.

It may be regarded as certain that, under all circumstances, the quantity of heat generated by the same amount of force is fixed and invariable. Thus, the quantity of heat that would raise one pound of water 1° F. in temperature, is exactly equal to what would be generated if a pound weight, after having fallen through a height of 772 feet, had its moving force destroyed by collision with the earth. The result of impact, when a body in rapid motion is suddenly stopped, is the development of a quantity of heat, distributed between the striking and the stricken body. Thus, the impact of a rifle ball against an iron target produces more than enough heat to melt the lead, but the capacity of iron for heat being greater than that of lead, the temperature of the latter is raised only about by one-third of the augmentation of heat. It has been calculated, from the known weight and rate of motion of the earth, that if our planet were suddenly met in space by another globe of equal size, capable of stopping it, the quantity of heat generated by the impact would be equal to that derived from the combustion of fourteen globes of coal equal to the earth in size.

This would be sufficient, not only to fuse the earth, but reduce it in great part to vapour, and if, after the stoppage, both globes should fall to the sun, the amount of heat generated by the two would equal that developed by the combustion of five thousand six hundred worlds of solid carbon.* In some such way, perhaps, the sun is fed, and that constant supply of heat produced, which afterwards passing out again into space communicates life in distant spheres.

Heat, then, is another form of motion. It is the motion of a mass reduced to the motion of the atoms of which the mass is built up. We cannot see this kind of motion, and in solid bodies, heated, but still solid, the particles must be regarded as in a state of peculiar vibration. As we increase the heat, we increase these vibrations, and at length the particles become separated from one another by a definite interval. Thus, in ordinary cases, heat first produces expansion or enlargement of the heated body, and if continued, the particles become, by degrees, so far loosened from the attraction of cohesion, that they roll and glide round and amongst each other. This state we call fluidity. While still held together they move laterally with freedom, and so long as this is the case they retain the fluid condition; but, if the heat be continued, the particles become at last absolutely uncontrolled by the force of cohesion, and pass into vapour. According to this view vapour, and the gaseous condition of matter, simply mean that state of matter in which the particles are thrown off into space with great and rapid motion. On the other hand, when a body is in this state, and meets with particles of other matter, whether of the atmosphere itself, or substances contained in it, the motion becomes gradually communicated, and apparently dissipated. The fluid and solid forms are re-assumed, and, unless new combinations have been formed, the matter re-assumes its former state.

All substances do not expand regularly by heat, and water is one of those in which this exception is very remarkable, and admirably adapted to the conditions of life on the globe. Bismuth, in like manner, expands when cooling to the state of solidity from a melting state. Just as, during frost, jugs with small necks, and leaden pipes full of water, are burst, so if melted bismuth be put in an iron bottle, and closed by a stopper, firmly screwed, the iron bottle will be rent asunder as the metal solidifies. India rubber, also, shortens on being heated. It is an important result, proved by experiment, that those substances which contract on solidifying, and expand on liquefying, require more heat to fuse them, according as the pressure to which they are exposed is greater. On the other hand, those which, like water, expand on solidifying, melt at a lower temperature when pressure is increased. These exceptional conditions are not without explanation, but it is not necessary here to do more than allude to the facts.

---

* Tyndall's "Heat as a Mode of Motion," p. 43.

The motion of atoms, as induced by heat, is extremely different under different circumstances, and is not the same in the various simple and compound minerals and rocks common on the earth. Some are said to *conduct* heat (or allow of its transmission through them) very readily, some are very bad conductors. In other words, the motion of the atoms (or the molecular transfer), which consists in each atom taking up the motion from its neighbour and sending it on to that next beyond it, is in some bodies rapid, while in others it is slow. Metals generally are much better conductors than other substances. At the head of the metals is silver, and at the other extremity is bismuth. If the conducting power of silver is 100 that of bismuth is only 2. After silver are copper (74), gold (53), brass (24), tin (15), iron (12), lead (9), and so on. Wood, stone, glass, clay, &c., are very much worse conductors even than bismuth. In all cases the rate at which the oscillatory motion of the atoms which represents heat is transmitted through substances depends on the mode in which the atoms are arranged.

It is important to notice that, in the case of many transparent crystals, heat travels more rapidly and readily along the axis of the crystal than in any other direction. There are, however, exceptions to this, for tourmaline conducts best at right angles to its axis. Wood, which is a bad conductor, in comparison with metals, conducts best in the direction of the fibre. Almost all animal tissues and productions are very much inferior to wood in the conduction of heat.

Electricity is conducted through different substances at almost exactly the rate, and in almost exactly the same order as heat. Heat, however, is developed in wire by a current of electricity, and the more rapidly the wire conducts heat the longer time will be needed to heat it by such current. Thus, while it glides with little resistance among and along the atoms of silver, heat is continually obstructed in passing through platinum, and rapidly brings it to the melting point. Again, a heated wire does not conduct so rapidly as one of the same metal that is cool.

The exact nature of the motive power developed or acting in electricity is not altogether clear, but that it is one of the modes of motion there can be no doubt. It has been suggested, with some appearance of probability, and with much ingenuity, that while heat may be a simple oscillation, electricity may result from certain compound oscillations. When two metals of different kinds are applied to one another, an electric current results. If the two metals, having different periods of oscillation, be placed in contact, a new rhythm or rate of oscillation will result, which is slower than either, and different from either. This is well illustrated in acoustics in the production of waves of sound resulting from two or more simple waves. This subject is still, however, under consideration, and the action of the electrical current, in passing through various bodies, requires to be much more carefully studied than has yet been possible to enable the physicist to illustrate clearly the state of the case, or the precise nature of the motion induced. Whatever it be, however, there can only be a slight and subordinate distinction between the different varieties of electricity, for the nature of the force is the same, whether excited in one way or another, and whether it be developed in currents passing through one kind of matter, or through matter in which the state of the molecules is entirely distinct.

Light, also, is an undulation or vibration of atoms existing in space, and therefore it is a form of motion. A pencil of rays that comes to us from the sun, and is submitted for examination, is found to be complex in its structure, and to be built up of clusters of rays, some consisting of variously coloured light, some of magnetic force, some of heat, and some of peculiar chemical action. When broken up by a prism the image of the ray, or the visible spectrum thrown on a white surface, only marks an interval of radiant action, in which the radiations are so related to our organisation that they excite the impression of light.

But beyond this interval, in both directions, radiant power is exerted and obscure rays fall, those falling beyond the red ray being powerful to produce heat, while those falling beyond the violet are powerful to produce chemical action.* The ray of light is the vibration of an all-pervading ether. The eye is adapted to receive impressions from a limited number of vibrations, waves, or pulsations, per second. There are other waves of more or fewer pulsations beyond these limits that are not perceived by the ordinary eye, but may yet be appreciated by other senses. There are others that our senses do not inform us of. So, also, in the same way there are waves that produce audible sound, and others of the same nature that are not audible. Under certain circumstances the latter can be made audible, and the former can become visible. A ball of metal, heated to a certain extent, has its atoms thrown into oscillation, but the waves are not rapid enough to be seen. Heated still further, however, the oscillations become rapid enough to be visible, and we say the ball is red hot. The visibility is only obtained when a certain degree of oscillation is reached. The sun itself is, no doubt, a source of heat and light, because of the enormous amount of oscillation of its particles, which communicate waves through space adapted to affect our organs. Light and heat, therefore, are essentially of the same nature, differing in degree.

There is a great difference between the waves of sound and those that, passing through ether, communicate ideas of heat, light, and chemical action. This difference may be understood in some measure by the statement, that the particles of the atmosphere, whose vibration produces waves of sound, move backwards and forwards. Those of heat and light on the contrary move up and down, disturbing the ether that pervades space, but not affecting the air that belongs to our earth.

All the rays from sun and stars, and the reflected rays from the moon and planets, are produced through the agency of this ether, which extends throughout the universe, and connects all the systems into one great whole. This ether may not be identical with material atoms in the ordinary sense. It rather surrounds, and comes between the atoms of all solid, liquid, and even gaseous substances. By the relation between the ether and the atoms of certain bodies, the waves that excite light pass through them without disturbing them.

---

* Tyndall's "Heat," &c., p. 255.

Such bodies are transparent. Other bodies allow certain waves to pass, but not all. These are coloured bodies. Transparency to one wave by no means implicates transparency to all, nor does transparency to light mean transparency also to heat. Rock salt allows much light, and almost the whole of any number of rays of radiant heat to pass through it. Ice is equally transparent to light, but allows hardly any heat rays to pass, absorbing and checking them almost all. In other words, the motion of a wave of heat passes through and among the atoms of rock salt dispersing them but little, and therefore checked but little, and a very large part emerges when the thickness of the plate is small. On the other hand, the motion of the wave, when it enters ice, tends to move the atoms of ice, and being almost entirely occupied in this interior work, but little heat or motion emerges. Glass, also, is nearly impervious to heat rays, though perfectly free to light rays. A glass screen, therefore, interrupts the heat, and becomes warm. Like ice, it is then itself a radiant body, distributing the heat in all directions.

The air around us, when dry, is in this respect like rock salt, for it allows almost the whole of any quantity of heat rays to pass through without performing any interior work. The particles of moisture contained in it, on the contrary, interrupt a proportion of such rays. And it is not only water or aqueous vapour that intercepts heat. Gaseous bodies of all kinds do so, though to a very different extent; the vapour of all essential oils—in other words, all scents, whether of flowers or animals—ammonia, olefiant gas, sulphurous acid gas, and, above all, ozone—that singular and little understood substance—these affect the properties of air to a marvellous extent, interfering in all cases with its perfection as a diathermic* medium, and increasing its power of absorption of radiant heat.

It is impossible to over-rate the importance of this fact. The air, when dry, allows almost the whole of the heat (or motion) derived from the sun to pass through it. And this is the case, whether the rays consist of vertical undulations exhibited in rays of light, or of that motion which is resolved into heat when its course is interrupted. But although light and heat so readily pass through, the air, if pure, would not be either illuminated or heated by them. The air, however, is never to be obtained at or near the earth's surface without the admixture of a large, though exceedingly variable quantity of material atoms, either of water, or resulting from the action of life, and all these alter its nature with regard to transparency to heat, so that a certain portion of the rays become absorbed, and the air is so far warmed. The larger the quantity of such vapour and gas the greater the absorption, and when the air is loaded with these substances, absolutely no heat passes through, the whole being stopped on its way. The earth, if hot, could radiate no heat whatever into space through an atmosphere of vapour, and thus could never cool so long as such atmosphere should endure. On the other hand, the sun's rays could not warm the earth if interrupted by such a film. The vapour itself would become warmed, and would itself radiate, and this would be quite independently of the source of heat. It is difficult to express how extremely minute is the proportion of vapour that seriously interferes with the passage of heat, and causes dry air to cease to be diathermic or transparent to heat. In such air as is obtained from the atmosphere in the open country on a dry and fine day the absorption of heat has been found by Professor Tyndall to be seventy times greater than the absorption of absolutely dry air.* It is to be regretted that there have as yet been no experiments made in different climates, for the sake of comparison.

---

* Diathermic means transparent to heat.

The energy of water, as a radiant, is not less remarkable than the completeness with which it absorbs radiant heat. "As vapour, it pours its heat into space, and promotes condensation; as liquid, it pours its heat into space, and promotes congelation; as snow, it pours its heat into space, and thus converts the surfaces on which it falls into more powerful condensers than they would otherwise be."† The removal of the aqueous vapour, even in any large degree, produces results of extraordinary magnitude on the earth. It renders almost uninhabitable large portions of the surface, and if it were absent, as it appears to be in the moon, no such existence as that we are acquainted with would be possible.

There is one very curious result of experiment concerning vapours, and their behaviour in reference to rays proceeding from some source of light and heat. It is that a gas or vapour absorbs those precise rays which it can itself emit,—in other words, the atoms which swing at a certain rate intercept the waves excited by atoms swinging at the same rate. Absorption means the transfer of the motion from the ether—the atmosphere of space—to the particles of matter immersed in it, and the absorption of any atom is exerted chiefly upon those waves which arrive in periods that correspond with the atom's own rate of oscillation. It is from a consideration of this fact, and an examination of the spectrum produced by the intense combustion of some of the metals, that the presence of dark lines in the solar spectrum, and that derived from some of the stars, is recognised as proving in these bodies the presence of some of the metals and metalloids that form part of the earth.

---

* Tyndall's "Heat," &c., p. 383.

† Ib. p. 389.

Chemical action is another form of motion. This is not less certain than that heat and electricity are of this nature. As heat separates the molecules from each other, and electricity appears to tend to arrange them in certain directions, so chemical action would seem to enable the atoms of various kinds to combine or separate and form compound or simple atoms. This is done by some part of each pencil of rays proceeding from the sun, and from other light-giving bodies. Every kind of chemical action is excited by electricity, and there is no more effectual means of effecting decomposition in difficult cases, than by passing a powerful electric current through a compound body. In this way water is reduced to its elements, and thus also many other great chemical results are obtained. So, also, all chemical action is affected by heat. Generally the action is thus rendered more energetic, but in some cases, as in ammonia and salts, it is weakened. Heat developed involves some chemical action, and generally some electric change. Chemical action involves the increment or reduction of temperature in the body affected, and every change of temperature promotes or excites chemical action.

But heat, also, and mere heat, excites the ordinary phenomena of electricity, for when two dissimilar metals are made to touch each other, or are soldered together and heated for that purpose, a current of electricity flows through the metals So, again, electricity produces motion by attraction and repulsion. Heat, as exhibited in the electric spark (which also shows abundant light), and in the voltaic arc, is more intense than is obtainable in any other way. Electricity produces magnetism by its mere passage through iron, as is illustrated every day in the working of the electric telegraph. It produces chemical affinity, as has been already pointed out.

We might proceed one step further, and show that vital energy, although not yet produced either by heat or electricity or by any other recognised forms of force, is, in fact, only another of these varied forms. Vital force is intimately connected with heat and motion, with electricity and with chemical force It produces and modifies all these so completely and readily, it produces heat so inevitably, it effects so much chemical change in forming combinations of elements not otherwise attainable, and its results are so closely simulated by the transmission of electric currents through the nerves when life has departed, that to this is attributed the very discovery of the existence of galvanism. In all these matters it is difficult to say where the relation lies, but equally impossible not to feel that a relation exists. As, however, none of the mechanical forces have as yet produced life, or renewed it when extinct, it is not possible to speak of this relation with the same absolute certainty as the others.

Thus, then, it appears that all the forces of nature are correlative and, so far as we can tell, interchangeable. The sun is a centre of force, inasmuch as that body is the centre of heat to our planetary system, and heat is motion. The heat or motion derived from the sun, and intercepted, is never destroyed, it is only changed in its mode of action. A part of it is converted into electrical and magnetic currents that circulate through the earth; a part of it results in chemical action within the earth, a part of it is represented by heat on the surface or in the interior, by motion, and by the circulation of water in the atmosphere; and a large part, we venture to suggest, may be occupied in producing those infinite and varied phenomena of life that surround us everywhere. But when all this is done the force is not destroyed. Force is absolutely indestructible, and can only be converted into some other form. An enormously greater force is needed to produce molecular change within the substance of solids and liquids than to move them in mass, but the molecular change goes on unseen, and often altogether unknown, as well as unfelt. Thus there is constantly within the earth an expenditure of force, resulting in molecular motion, that is almost unlimited in its amount and variety. By radiation the earth sends off into space the excess of motion communicated, and it also attracts every other body in the universe according to its mass and distance.

We have pointed out at the beginning of this chapter that a knowledge of the forces that act upon matter is desirable to enable the student to comprehend the nature of physical geography. It is only thus that he can at all enter into the consideration of the peculiar groups of facts that make up meteorology, and those that are most interesting in hydrology. The atmosphere and all the results of the admixture of water with it, and the movements by which winds and storms are produced within it, can only be understood by the light of this knowledge. The waters of the ocean and their circulation are equally dependant on the laws we have been tracing. And if all the physical forces are, as we have assumed, correlative and interchangeable, we may hope one day to disentangle the complicated phenomena of electricity, and deduce them all as parts of the great system of motion affecting matter everywhere and for all time. Without this identity of all forms of force there could be no such hope. It is only by clearly understanding the relation of electricity to the other forms of force that the physical geographer can learn the nature of those changes which have brought the earth to its present state, and that are still active in producing further change.

Before concluding this chapter, we must make special mention of those polar forces generally, which we have already referred to under the names of electricity, galvanism and magnetism. The general result of the passage of currents of these forces through the earth would seem to tend to the arrangement of the molecules in a direction nearly parallel to the earth's axis, and strictly parallel to an assumed magnetic axis. This singular tendency affects chiefly certain metals, of which iron is by very much the most striking example. It is illustrated in the compass needle, whose important practical use is familiar to every one. In a natural state sometimes, though rarely, iron is found so far affected by the polar force as to arrange itself, when freely suspended, in a north and south direction. Obtained artificially, and in a pure state, iron readily becomes magnetic by the passage of a current of electricity through it; but when the current ceases to pass along, it ceases to be magnetic. Combined with a little carbon, however, and converted into steel, the metal becomes magnetic with greater difficulty and more slowly, whether by contact, current, or friction, but when once a current has been established, it remains. Hence the various uses of magnets of different kinds, and the advantage of using soft iron when a current requires to be completed and broken every instant, as in the electric telegraph, and steel when the current is required to continue, as in the compass needle. This peculiarity is very instructive, and suggests important conclusions with respect to the mode of action of the physical forces.

Besides iron, the following metals are magnetic, but in a much smaller degree:—nickel, cobalt, manganese, chromium, cerium, titanium, palladium, platinum, osmium. In certain combinations copper and zinc may become magnetic, though in a simple state they are not so. In all these metals the molecules arrange themselves parallel to the earth's axis when exposed to the electric force, while, on the other hand, the atoms of all the other elementary bodies, when exposed in a similar manner, place themselves at right angles to the earth's axis or equatorially. Of bodies characterised by the latter arrangement, bismuth is the most remarkable, and after it come phosphorus, antimony, zinc, tin, cadmium, sodium, mercury, lead, silver, copper, gold, arsenic, uranium, rhodium, iridium, tungsten. All these substances are said to be *diamagnetic* in contradistinction to those that are *magnetic*. It requires extremely powerful currents to render the phenomena appreciable.

The direction assumed by a magnetised bar of steel freely suspended above the earth is not true north, except when the bar is suspended in one of two lines on the earth's surface, called *lines of no variation*, one in the eastern the other in the western hemisphere. The western of these lines at present passes in a south-easterly direction from the 60th parallel of north latitude west of Hudson's Bay. It crosses the American lakes, a part of north America, and the Atlantic ocean, and cuts the meridian of Greenwich at the 65th parallel of south latitude. The eastern line commences in the 60th parallel of south latitude, is traced westwards through the Indian ocean towards Bombay, thence runs eastwards across China, and northwards through the Japan sea, and reaches the latitude of 71° N. Thence it makes a bend to the south and terminates in the White Sea. The position of these lines, however, is constantly shifting. In the years 1657 to

1662 the western line passed through London, and therefore at that time the compass-needle pointed true north. Before that, the variation had been to the east, and diminishing. Since then, till the beginning of the present century, it increased till the divergence amounted to 27° 18′. It is now diminishing, and is about 26°. At Greenwich, in the year 1860, it amounted to 26° 20′.

There are, also, remarkable and periodical variations in the amount by which the needle is deflected, or bent away from a true horizontal position when freely suspended. The force of the earth's magnetism determines this. This variation is smaller in amount than the other. It has periods of increment and decrement, and has long been decreasing. In 1720, at Greenwich, it amounted to 74° 42′; in 1820, 70° 3′; and in 1860, 68° 32′. There is a daily and monthly change in this magnetic intensity. Thus the intensity is greatest in December and June, when the earth is nearest to, or farthest from, the sun, and least at the equinoxes, when the position of the earth is as far removed as possible from these extremes. The daily variation is greatest in summer and least in winter, least when the sun is near the meridian and greatest at sunrise and sunset.

Magnetic storms occasionally occur. These consist in sudden and great derangements of the electrical currents that pass through the earth. They interfere with the working of electric telegraph wires, especially when the line is laid in certain directions. The disturbances are often indicated in the higher part of the atmosphere by the appearance of vivid flashes of light, called *aurora*. Such an appearance in the north is an *aurora borealis*, and in the south *aurora australis*. There have been cases in which auroræ, from the north and south poles, have met midway under the equator. Great magnetic disturbances are usually accompanied with, or followed by, storms of wind and severe hurricanes, as will be noticed more at length in the chapter on which winds and storms are particularly treated on.

CHAPTER III.

THE SUCCESSION OF ROCKS.

To understand physical geography, it is as necessary to have some preliminary acquaintance with the results of geological investigation as it is to know what astronomers have determined concerning the earth in its planetary relations, and what physicists have made out concerning the nature and mode of action of physical forces and motion. Geology itself must be based on a sufficient knowledge of physical astronomy and physical geography; but some account of the results of enquiry in this direction in an introductory chapter will be useful to the general reader, reminding the student of many important facts already learnt, or informing him concerning them if he has not yet entered on the study of that department.

The elements of all the natural sciences depend so much on each other that it is impossible to understand one alone. Some general knowledge in the possession of the reader has been already assumed, but it seems desirable to give a sketch of geology in a very brief way. Let us, therefore, now address ourselves to learn the ascertained results of enquiry concerning rocks and their super-position, the succession of strata, and the changes that have taken place in rocks since they were first formed.

All these enquiries belong to GEOLOGY, properly so called. Important and highly interesting facts, determined with reference to the remains of animals and vegetables that have once lived on the earth, and have left indications of their former nature, form another science—PALÆONTOLOGY. This is a means to an end, so far as pure geology is concerned; and thus we postpone giving an account of these results till a future chapter, when we will consider the *succession of life*, after duly illustrating the natural conditions under which life exists on our globe.

I.—ROCKS AND THEIR SUPER-POSITION.

The rocks that compose the earth's crust are necessarily made up of the minerals at the surface, either formed there or brought to the surface at various times and under various circumstances. These minerals are either the elements already spoken of or the combinations of elements enumerated in the last chapter. Of the large number of known elements it is a fact well worthy of attention, that a comparatively small proportion are found in the materials always under our feet; while on the other hand some, both of these and tho others, seem to be universally distributed in nature, not only throughout all the bodies of our system but even in the very stars themselves. Very few of the possible combinations of these elements are found at all in nature, and still fewer are common. Thus the complication and difficulty that might have been anticipated do not exist, and a singular simplicity reigns in reference to the minerals that make up rocks. It is, of course, impossible even to speculate as to whether this simplicity prevails out of our own planet.

In almost all accounts of the earth's structure there is one rock that is usually referred to as fundamental. It has been thought that this rock underlies all others; that it is always so nearly the same as to need but a single name; that it forms mountain crags and summits because it has been thrust through other rocks by violent subterranean action; and that if all the other rocks were removed this would stand out boldly as a skeleton of the earth, marking still where mountains stood, and showing, in the depressions between the mountain ridges, the site of existing valleys. This rock is granite. It is a convenient name, but it includes a number of very dissimilar things. It also greatly helps to conceal an ignorance which will be long indeed before it is dissipated. But we must begin by reminding the reader that granites are not simple rocks. They are, on the contrary, the most complicated of all. They have been formed probably at all times and with all kinds of materials, and from the debris of all other rocks. But inasmuch as the elements composing all rocks are chiefly silica, calcium, and aluminium, combined with oxygen and hydrogen, and mixed up with small proportions of a few metals and metalloids, granites do not show much variety of ultimate composition beyond that which belongs to a difference in the proportions of the ingredients.

And since granite has been formed under circumstances of temperature and pressure very different from the ordinary compounds which form superficial rocks, many crystallizations and combinations have been effected which are for the most part distinct and characteristic. Granite, therefore, though really made up of common minerals is not like them. A very small difference, not only in composition, but in the heat at which the compound was formed, in the pressure to which it has been exposed, and in the time during which it has been exposed to the influence of the physical forces under certain conditions, is enough to have produced great and essential differences of appearance and behaviour. Some granites are in large, some in small crystals: some chiefly consist of one kind of crystals, some of another; some are of one colour, some of another; some are hard, others rotten; some beautiful, others formless and colourless.

But not only is there this difference in granites from different places. In the same rock, as exhibited in one district, and even in a small hill, it is very seldom indeed that there are not marked difference in texture, grain, colour, hardness, and other properties within a very few yards. In a quarry, where the rock is worked on a large scale, there are only particular parts (*veins*, they are called) that are valuable. The rest is generally inferior. It is too hard, or too rotten, or has not the right tint or grain. If looked at carefully, it will be found that there are real and manifest differences. And this is natural enough if we regard the granite as a re-composed rock, resulting from the alteration of certain limestones, sandstones, and clays, exposed to an equable and high temperature for a long period. There is, indeed, no evidence whatever that granite or any similar rock exists at extreme depths. It may do so, and perhaps it does; but certainly the varieties it presents are hardly consistent with the entire uniformity of the rock. Still less do they prove it to be that which underlies all the rest. They rather suggest that each case in which granites appear has its own local history.

Granites, and the rocks so called, consist always of a mass of crystals, generally of quartz and felspar, with crystals of mica, all embedded together as in a paste. The mica is often absent or replaced by hornblende. The felspar is of various kinds. Even the quartz differs. But in a general way there is in all these rocks an excess of silica, and but a small quantity of carbonate of lime. Not that carbonates of lime are absent, but they are much less abundant in granitoid rocks than in some other combinations.

Granites and similar rocks form a definite group, and whether always original and early formed, or always produced in recent times, or belonging to all time, which is most likely,—whether always simple or always derived, or sometimes one and sometimes the other,—they are much too important to be neglected. They are found in most countries. They are often, but not always, prominent; and in mountain ranges they sometimes form the high serrated ridges or mountain peaks. They rarely offer any appearance of true stratification, or alternation with other rocks, but they often exhibit a rough kind of lamination on a large scale, and instances are not unknown in which granite and other rocks succeed each other, and the granite is not the underlying material. All granites are particularly liable to exhibit lines of fracture, and to contain fissures or gaps, which are often of considerable magnitude and are of all dimensions. These fissures are not unfrequently filled up with foreign materials crystallized and systematically arranged. Such fissures are *mineral veins*. When they contain metals, or earthy minerals containing metals, they are called *lodes*. Lodes in the same district are generally in sets or groups, parallel to and at right angles with one another; and in these cases the different groups of lodes often contain different metals. As recipients of valuable metalliferous minerals, the fissures in granite have been carefully studied, and their history is to some extent known and recorded; but there are innumerable instances of fissures and narrow cracks admirably systematic in their arrangement, but not metalliferous. These, though not less instructive, are less profitable, and have therefore been less accurately known and described.

Many varieties of granite are quarried, and their appearance is thus rendered familar. As a building material, some kinds of granite are too hard and too costly in working to come into extensive use for ordinary purposes. For certain purposes, the better qualities have been used from time immemorial. They supply the material for those constructions that are meant to endure for ages, and also for great public works where strength is needed and expense of construction need not be considered. The great temples of Egypt have handed down to us detailed statements of the customs, peculiarities, art, and even history, of many parts of northern Africa for several thousand years. Hieroglyphics cut in granite, and preserved owing to the durability of the material, communicate this information. The material used is now called *porphyry* (from the colour of some varieties) or *syenite*, from Syene, the name of the place where are the most remarkable and the oldest quarries in Upper Egypt. Both are varieties of granite. In our own time and country, the quarries of Peterhead near Aberdeen, and others in Cornwall, have supplied granite of extreme beauty, and in enormous quantity, for bridges, quays, and other public works, besides shafts of columns and polished slabs for decorative purposes. The quantity of the same kind of material used for paving purposes in London alone amounts to many hundreds of thousands of tons annually. Throughout Europe, but especially in the central and northern countries, rock of this kind may be found at intervals, either at the surface or at a comparatively small distance below.

There is no sufficient reason to induce us to believe that granite of any kind has existed in a state of absolute fusion. All the appearances that favour this theory, such as veins of granite thrust out like fingers into the interstices of other rocks, appearing sometimes to have affected them by intense heat, are capable of some other explanation. Assuming granite to be a rock formed by chemical change, acting under peculiar conditions of temperature and pressure for a long period, it is not too much to assume that the kind of crystallisation which it presents to us might not only occupy fissures in the rocks adjacent, but that the walls of the fissures might be in some measure affected by the work going on. There is no doubt that the materials composing all varieties of granite have been in a state of intense heat, capable of moving among themselves, and under heavy pressure; and this can well be accounted for by the natural increase of temperature observed to take place in descending to any depth below the surface. That this is due to a burning nucleus, there is no proof whatever. On the contrary, mathematical investigation seems to prove that the solid crust of the earth must be at least 2,000 miles, or half the radius, in thickness.

Incontestable proof of the association of water with granite, and also with most, if not all, the crystalline minerals occupying veins and fissures in it, is afforded by a careful examination of the minerals under a powerful microscope.

Like most crystalline rocks and minerals, thin slices of granitic rock abound in very minute bubbles and cavities. These are so numerous as to amount to millions in a few solid inches of the mass. Some of them are full of gas, but most of them contain water, either pure or holding in solution more or less of the salts of sodium and other alkaloid bases. By an ingenious and laborious method of investigation, these blebs and their contents are made to reveal the circumstances of heat and pressure under which the whole mass was formed.

There is another class of rocks apparently formed with the agency of great heat, but much nearer the surface, and in which the absence of water in the cavities justifies the conclusion that they have been melted near the earth's surface. These include some of the porphyries and the rocks called trap and basalt. They are derived from and dependent entirely upon adjacent volcanoes, or openings by which rock melted by some local cause of intense heat at moderate depth below the surface can reach the surface, and exercise there the effect due to the amount of chemical action going on below. That basalt is an ancient lava, or rock poured out at the earth's surface in a melted state, instead of being deposited from water, there can be no doubt. The two rocks agree in all important respects. They differ chiefly in the fact that the true basalts may have been erupted under water, while those modern lavas we are able to examine are sub-aërial. Most of the sub-aqueous lavas of the present day are still buried beneath the waves. Sometimes, as in the recent eruption of Santorin (January, 1866), the lava poured out under deep water forms shoals and ultimately islands, actually reaching above the surface. But even here the lava we see is sub-aërial, not sub-aqueous.

In point of super-position, by which is meant the mode in which rocks rest upon one another, there is practically no difference between those in which great heat and powerful chemical action have altogether removed all traces of merely mechanical origin, and those where mechanical origin is still perfectly manifest. Basalts lie over the ordinary deposits of the sea, or on the water-worn and weather-worn surfaces of the land, and soon become covered up by or gradually pass into other material, which is perhaps for the most part derived from them, or which may be entirely brought from a distance. So it is with granites and such like rocks. But in the case of granites, they have been formed at so great a distance below the surface, as well as at such high temperature, and so slowly, that the adjacent rocks have almost always lost the distinctive marks of their origin. Still, granites alternate with rocks, which not only are not granites, but which are to all appearance of strictly mechanical origin.

Even when there is no alternation, granitic rocks are often in contact with compound rocks of the same general nature, but altogether mechanical in their arrangement. The crystals that make up granite may be arranged in beds or strata, so that the resulting rock might be called "stratified granite." Such masses need not consist of the crystals of granite broken up and re-cemented. When thus independant they are recognised by geologists under the name of *gneiss*. Such rocks would seem to be rather partially-formed granites than granites once formed and re-arranged. The two rocks pass into one another, veins of completely-formed granite occasionally entering the gneiss. Decomposed granite is a very different rock, and there is no probability that it could be converted into any variety of gneiss. It is very abundant in certain districts, and, like granite, it presents great differences in appearance. Though sometimes very hard and tough, gneiss does not seem well adapted for building purposes.

From the mode of its formation, it follows that gneiss is more or less stratified. It is often contorted and confused in its stratification, but the traces of mechanical arrangement are clear. It occasionally alternates with granite. But much more frequently it connects itself with rocks of somewhat more clearly-marked stratification, in which the granite element is no longer traceable. These are *schists*—splitting rocks—often more or less clayey in appearance, often highly crystalline in texture. They vary greatly in different places. They are widely spread, especially in mountain districts, and they often occupy the place which the popular theory of the origin of granite, if correct, would require that rock to take. It has hardly been suggested, however, that schists are due to other than a mechanical origin, although they are often loaded with crystals such as are found in the veins and fissures of granite.

They also abound with systems of fissures, and these often contain metals, though rarely the same as those common in granite fissures in the same district.

Schists pass into the well-known rock called *slate* or *clay-slate*, but this rock, in its most characteristic form, has the peculiar property of splitting into films with parallel faces, more or less thin according to circumstances, and capable of being made use of for various economical purposes. The splitting of slates is, however, not due to crystalline structure. It seems rather the result of enormous squeezing to which some varieties of clay have been exposed in the changes of position that have taken place during the gradual elaboration of the earth's crust. Great squeezing will give to many substances this peculiar arrangement of the parts, whereas no known process of stratification or crystallisation will produce the appearance of slate in any kind of clay. The marketable qualities of slate occupy but a very small part of any extended mountain mass of the rock, but this is owing to local causes, with which the student of physical geography need not trouble himself. It is enough to know that slates, though not exhibiting their stratification in their splitting planes, (planes of cleavage), almost always betray their origin by an appearance of bedding. The discovery of the bedding enables the geologist to understand the position of slates relative to other rocks.

Generally speaking, it may be understood that a group of rocks consisting of granite, gneiss, schists of various kinds, and slate, arranged more or less accurately in that order, seems to form the basis of such rocks as are presented for observation at the earth's surface. All but granite have certainly been accumulated by some slow process of deposit, probably from water. Granite, itself, may probably have had a similar origin. In granite, however, the origin, whatever it may have been, is now quite obliterated by a complete re-formation and re-construction of the mineral mass, while in the other rocks the formation and construction are traceable, however obscurely. The various rocks also are super-imposed, that is, they are heaped one on another in a manner often regular, though sometimes irregular. They are rocks that are not exactly identical when compared from different districts, nor even from points a few miles asunder in the same district, and yet they can be recognised conveniently by the same general name.

They are, on the whole, the lower rocks, for although they may, doubtless, be of any age, they are the lowest that appear in the district where they abound. If there is anything older in such district it does not appear in its own form, but rather, as far as can be traced, in some variety of one of these.

Over such rocks as we have described, there are generally heaped masses of greater or less extent, consisting of limestone, sandstone, or clay, or some admixtures of these. Very often the only rocks visible or traceable over areas of many hundreds or thousands of square miles are nothing more than repetitions of these masses. They are not always in the same state, nor do they extend uniformly. Sometimes they alternate with one another. Sometimes one prevails largely, almost to the exclusion of the others. But these are the materials that cover the rocks already alluded to, and on examination it will be found that they are generally derived from them. They are the fragments of the granites, the schists, and the slates, broken away by the action of the weather in mountain districts, ground down to a fine powder by the rivers or the waves of the sea, sifted, grouped and deposited by the water as it passes along to the sea over the earth's surface, or as it moves along in quicker or slower currents over the ocean floor. Sometimes, indeed, they are mere accumulations made by animals, the result of the exercise of a power that can select certain solid substances, such as carbonate of lime, phosphate of lime, or silica, indestructible after the death of the animal. Such are coral islands, certain kinds of mud at the mouths of rivers, fragments of shells and bone, or beds of coal. Sometimes they are accumulations of vegetable matter, such as beds of coal and lignite.

Thus, then, it will be seen that silica, lime, and clay, with a per-centage of iron and other metals, of soda, potash, and other alkaline bases, and of carbon, which usually form stratified rocks, must, if this statement be correct, be also the substances of which granite and gneiss, schist and slate are composed. Chemical analysis confirms this conclusion, and we thus see that by the constant alternation of combination and decomposition of a few elements and minerals the whole crust of the earth has been built up, and that the same kind of work has been going on from the first commencement of the earth's existence as a habitable globe.

II.—ORDER AND DISTURBANCE OF STRATIFICATION.

The stratified rocks, whose history forms so important a part of geology as to have been sometimes almost confounded with geology itself, are to be found in most parts of the world, and are due almost exclusively to the action of water on solid matter with which it is in contact. Without water there could at any rate be no such strata as those with which we are familiar. But neither could these strata have been available for study if there had been no movements affecting some parts of the earth's crust and not the rest, and no upheavals, depressions and other movements, bringing to the surface what was once far down at the bottom of the ocean. Nor could we have had the existing evidence of the earth's history if rocks had not, from time to time, been buried to a depth of tens of thousands of feet, or if strata once formed at the surface had not been depressed till they were brought within the influence of causes only acting far beneath, out of our sight.

'Strata' is the name given by geologists to successive deposits made by water, which has conveyed heavy material for a certain distance, owing to its motive power, and then left its load behind when its motion became checked. Owing to the constantly shifting conditions of deposit, it is rarely the case that any great thickness of sand or mud is accumulated without some interruption, or some cause of slight modification. Such causes produce the usual phenomena of beds, layers, or *strata*, familiar enough to every one who has examined recent accumulations of any kind. But it must be clear that the strata generally have been deposited horizontally, or very nearly so. No great and continuous deposits in water can be formed on a steep slope, and the more steady the heaping, the larger the quantity, and the slower the operation, the more certain is it to result in horizontal layers. Were the strata now in the position in which they were deposited, it is, therefore, clear that we could know nothing of their nature below the lowest point reached by artificial sinkings. This would entirely prevent our drawing any conclusions as to the rocks of which the earth's crust is made up. But practically we are enabled, by crossing England from east to west, to cross the *edges* of a series of strata in our own island, whose total *thickness* must greatly exceed the height of the loftiest mountain in the world, although in the British islands, there is no point five thousand feet above the sea. Other countries exhibit more or less favourably similar results.

The means by which we are thus enabled to investigate what has been below the surface without leaving the surface, and learn what nature has done in the deep recesses of the earth, are simple enough. The strata have been deposited generally at moderate depths, and often close to the contact of land and water. By the agency of forces still in action, apparently connected with earthquakes and volcanoes, parts of the bed of the ocean and of the land are, from time to time, subjected to depression or elevation, slow and interrupted, but continuing for a long period, and acting over a very wide area. By these means what was once a deposit becomes not only covered up with newer deposits of the same or different kinds, but is carried gradually within the influence of high temperature, and of the currents of electricity and chemical action there constantly and regularly at work. Still as they are lowered to greater depths, and come under the increased pressure of fresh deposits above them, they become more and more changed, and from mere heaps of incoherent mud, loaded with impurities and foreign bodies, they become rocks in the ordinary sense of the word, hard, compact, and banded. We also find that the impurities and foreign substances are often separated from them, and made to combine in definite lenticular masses, or in parallel layers. Such is the first chapter in the history of geological formations. There is an accumulation and a burial, and the buried mass acquires organisation and system, and a distinctive character.

When thus formed the strata may remain covered up for an indefinite period without change. But the time comes when the reverse operation takes place, and the whole mass rises. Then commence systematic fractures and irregular upheaval. The subterranean force, whatever it be, and however it may act, is partial, though very powerful. It breaks the strata, and lifts them up more in one place than another, so that they become tilted and faulted (the broken edges separated). This may take place to any extent, even until some of the deposits are fairly overturned, others being left vertical, or nearly so. For the most part, however, the order is correctly preserved, but owing to the inclination a number of beds, originally overlying one another vertically, may now exhibit their upturned edges. It must not, indeed, be supposed that these edges are left exactly as they first appeared above the surface. The work of elevation has probably commenced beneath the sea, or within the limits of action of running water. The elevated mass, therefore, will have been exposed to the action of powerful causes of change while it was rising above the waves, and the irregularities and ridges will be pared away, leaving a smooth surface, but still showing a section from the upper to the lowermost beds, and laying bare long series, each many thousands of feet in thickness.

There is no definite order in which the various materials are arranged in stratified rocks. There is, also, no exact identification of the various beds that are contemporaneous, by any mineral characteristic. Throughout a long series, limestones, sandstones and clays succeed each other, each group differently affected by the elevating force, each having some peculiarities of its own, perhaps, but still each being only a repetition of the same materials, deposited at one time, removed at another, and worked up over and over again. But generally some small portion of each is retained as a sample, to be handed down to future time, and tell the history of the succession of deposits.

It must not be supposed that the deposits thus described are always vague and doubtful in the evidence they bear as to the state of the world at a former time. They are, on the contrary, often precise and definite. They contain, besides the minerals of which they are chiefly composed, numerous proofs of the state of life at the time they were formed. They even consist, sometimes almost exclusively, of organic remains, or, in other words, of the constructions and solid framework of what were once living beings. They are thus capable of identification, and they teach us the order of succession in different countries at the same part of the history. Nothing is more remarkable, nothing can be more useful, and nothing can be more accurate and definite than this means of determining succession, and comparing succession in different parts of the world. It must not be supposed that this evidence, striking and prominent in some deposits, where it is derived from the presence of fossils, is less valuable in others, where the fossils are few and difficult to understand. Far down in the series, below many of the slates and schists, and even granites—among the most ancient of all rocks, if we may judge by super-position, there are indications of life. The kind of life is obscure, but the organised structure is unmistakeable. Schists, largely developed on the banks of the St. Lawrence, in North America, and thence called Laurentian, are of enormous antiquity, and have yielded this evidence. Similar schists in Scotland, very far below thick deposits which, till lately, were thought unfossiliferous, have been found to offer the same evidence. The rock in which these fossils occur is almost a serpentine; it is a magnesian rock greatly altered. The nature of the organic body is obscure, but it offers nothing to justify the conclusion that the sea was then different, or the land less extensive than it is now.

And from this old Laurentian rock we must rise through a long succession of deposits before we reach the Cambrian and Cumbrian grits, slates and schists, of our own island, and then, again, up through some thousands of feet to the Silurian rocks. Vast gaps indicating the lapse of long periods of time are indicated in all that we know of these older rocks. They are all much altered, their organic contents are only here and there to be found and recognised. They have generally been broken and distorted even in the countries where they are most abundant. These gaps are breaks in the geological succession. They become less marked as we reach the newer formations, made in more recent times; but between some rocks of comparatively modern date there are interruptions of a very remarkable kind.

It is altogether a broken history, then, this account of the succession of rocks. But, fragmentary as it is, it contains a clue, and the only clue that exists, to the real history of creation on our globe. Some geologists believe that they make out a continuous history, showing life in its first introduction in a simple form, gradually becoming more complex, presenting itself in constantly advancing types of organisation, and culminating in man. We do not advise the student to tie himself to any such theory. The evidence in support of it is chiefly negative, and it would seem more unsatisfactory than it does were it not for the natural desire and instinct of men to discover a beginning, a middle, and an end, and not rest satisfied with that which the evidence really justifies. All we can suggest in the place of this faith is to hold back from definite conclusions till the facts are more abundant, and their connection with each other more clear. But we are here considering the succession of rocks, and not the succession of life, and must not be led away by considerations that belong to another chapter.

There are three great recognised groups of rocks which have been known to geologists, and are familiar to geological students. They are called PALÆOZOIC, SECONDARY, and TERTIARY. The name PALÆOZOIC is given, because the group so called includes the oldest forms of life. It is convenient, and not theoretical. The other names (occasionally replaced by MESOZOIC and CÆNOZOIC) have the same advantage. They have little meaning that involves any theoretical view. They assume only certain safe conclusions from sufficient evidence, namely, that two important natural breaks in the succession took place, so far as rocks are at present known, and that of these the first is represented by the interval between palæozoic and secondary, and the other that between secondary and tertiary. That such natural breaks have sometimes occurred in every place is only another mode of saying that much time has often elapsed, and many events have taken place between the deposit of two rocks that now succeed each other. The time is indicated by the change in the kind of animals or plants whose remains are found in the rocks. The events are either the result of the wearing away of part of the underlying rock before the newer was super-imposed, (indicating also a lapse of time) or the result of upheaval, depression or fracture, tilting and disturbing the older and lower without affecting the newer and upper rocks.

Of the oldest group of rocks there are many sub-groups of great importance. Many of these probably represent a much longer duration of time in their formation, and more geological events than the whole of the middle or newer groups, but this at present has not enabled geologists to propose with any certainty a fresh arrangement. Besides the *Laurentian*, or oldest, and the *Cambrian* and *Lower silurian* groups—the latter of which admits of very important subdivisions—the *Upper silurian* and *Devonian* rocks are distinct, and well marked, the latter differing in its mode of representation, and in organic contents, according to local circumstances. After this comes in the great *Carboniferous system*, commencing with a vast and important accumulation of coralline and shelly limestone, and terminating with innumerable beds of mineral fuel widely spread over most parts of the existing land. The *Permian rocks* complete the palæozoic series.

These grand subdivisions present examples of all the common rocks. In the oldest of them, where the masses have been longest exposed to causes of change, limestone seems less abundant, but there are important calcareous zones in the upper silurian, and in all the more modern groups. Limestone, sandstone and clay, in a state more or less changed, and more or less mixed up with each other, occasionally passing into distinct minerals containing magnesia and iron, occasionally loaded with crystalline minerals and metalliferous ores in their fissures;—these are the materials that make up the older rocks. In one part one variety prevails, in another, another. Here we see a thickness of thousands of yards of sandstone alternating with bands of coal and belts of ironstone. Thousands of yards below are muddy argillaceous limestones, in whose crevices lead ore is abundant. Both are underlaid and overlaid by an enormous thickness of shales, representing the clays of an early sea very slightly altered. Everywhere sandstones appear, coarse conglomerates, consisting of boulders of all sizes mized with finer sand, scarcely holding together; hard grits that will rather break across the pebbles of which they are made up than fall back into the original heap of detritus; white sandstones, pure, fine, even-grained and regular; other sandstones, yellow, brown, or red: rough, irregular and coarse; and crystallised quartz associated and alternating with building-stones and flag-stones. Such is the succession of rocks, as made out from an examination of the whole series. Confused and difficult to understand of themselves, they fall into order and arrange themselves easily and perfectly with one touch of the magic wand held by the palæontologist. Organic contents reveal the place in the series to which each belongs, and geology becomes definite when it can avail itself of the help of the sister sciences of zoology and botany.

Secondary rocks are also subdivided, and they exhibit breaks less perfect, perhaps, and involving a lapse of less time than do those between the different members of the palæozoic group, but they are not, therefore, less easily studied. The rocks, too, of the secondary period are in England, though not always elsewhere, more in the condition in which they were deposited, and more accessible than the palæozoic. In them limestones are prevalent. The clays are generally more or less calcareous, and even the sandstones are cemented by carbonate of lime. The prevalence of carbonate of lime during the deposit of the familiar rocks of the middle and newer part of the secondary period is remarkable, and may be called characteristic, so long as England alone, or even Western Europe, is examined. But this is not so everywhere. Perhaps the real cause may be that these rocks being newer, and not having been so depressed as to come within the influence of chemical action in the deep recesses of the earth, they are less changed than the others. Where, as in the Alps, there has been sufficient alteration, and they have fallen under the same influence, the result is so similar that the slates and sandstones of the later secondary can hardly be distinguished from those of the older period.

The chief subdivisions of the secondary rocks include sandstones at the base, so closely resembling the newer Permian sandstones of the palæozoic period, that they are with difficulty distinguished from them. These sandstones abound in rock salt. Over them are bands of clay (*lias*), containing in parts a large quantity of calcareous matter, often collected into bands, and sometimes passing into an impure white limestone, especially in the middle part. Next above the lias is a remarkable series of limestones and clays, which are so much developed in England, and come to the surface over so large a part of our island, that they have attracted great attention, and are very familiar. They do not, however, represent a longer period of time than very much smaller deposits of older date, barely seen in England. The *Oolitic series*, as these English deposits are called, forms the middle part of the secondary group of rocks, and its limestones are remarkable for being collected into little concentric grains, like the roe of a fish. This construction of the limestone is mechanical, local, and comparatively unimportant. Over the oolites are sandstones in some parts of Europe, but in England the upper beds consist of a fresh-water deposit on a somewhat large scale, and as most of the principal older deposits are of marine origin, this becomes especially interesting. It is called *wealden*. At the top of all are remarkable deposits of a peculiar kind of limestone, fine grained, soft, and apparently little changed from the original deposit of soft calcareous mud. But this bed—the *chalk*—has its own history, and the flints which abound in it are peculiar, and have been elaborated since the mass was accumulated.

There is almost everywhere a singular want of connection and mutual relation, in a geological sense, between the chalk and any rock lying upon it. The oldest of the overlying rocks seems to be a limestone, differing from it but little, except that the latter and newer is loaded with one kind of fossil, while the chalk contains an equally abundant series of others very different. The rocks of the tertiary period, however, like those of the secondary period, consist largely of limestones, and to a less wide extent of clays, marls, and sandstones. In the south of Europe, in Asia, in South America, and in some parts of North America, these rocks are more extensively developed at the surface than any other. In England they are comparatively poor and cover but little ground. Clays in the neighbourhood of and beneath London are the chief representatives of the older members, and shelly sands on the coast of the eastern counties of the newer. Over all,—distributed irregularly not only in England, but throughout northern Europe and the northern part of North America,—is a wide-spread deposit of gravel, sand and boulders, sometimes very thick and continuous, but often thin and interrupted, and consisting of material removed from a distance, probably by the action of ice.

Such is the general succession of rocks. Irregular accumulations, each one derived from some that were older:—continuous deposits, more or less broken or disturbed:—fragments of rocks, once widely spread;—such, in a few words, is the statement we have to make. But through all these runs a thread that serves as a never-failing clue, for the succession of rocks connects itself with a succession of life, and a history is elaborated out of material at first sight unpromising. The history is complicated, but it is not doubtful. The sea, the rain, and the wind—the ever-acting causes that promote change at the earth's surface—have always promoted similar change. Animals and plants have always lived, and at all times, as now, they have been perfectly adapted to the circumstances of existence. To understand the changes, and causes of change, we must study the earth as it now is, and as it is daily modified; and thus to understand geology and its conclusions aright, we must learn physical geography.

III.—METAMORPHOSIS.

Before concluding the present chapter and this general outline of the facts of geology, a word or two must be said on the nature of those changes that have taken place in the texture of certain rocks which, being deposited as mud or sand, have since become limestones, sandstones, or clays; slates, schists, or quartzites; marbles, granite, gneiss or basalt; as we find them now in the earth.

These are all modifications or reconstructions of the same elements. They can be reduced to these elements, and we can trace the progress of modification in separate instances. It is, however, essential, that the course of change in rocks should be understood, for few things are more unlike than rocks, and the deposits obtained from them by the ordinary action of existing influences. The student should also be able to connect the simple rocks, as deposited, with resulting rocks formed out of them, and this is not always easy.

No sooner is a deposit left by water than it begins to change, for it is almost immediately exposed to some fresh action of forces in the earth. It begins to part with some of its moisture and becomes drier. In drying it occupies a smaller space, and, contracting, it cracks. It is soon covered over by fresh deposits. It is made up of various ingredients, and these induce chemical action or currents of electricity. The whole is exposed to such currents of earth-magnetism as are known to course through the earth. In some cases the mass is gradually exposed to increased pressure as it sinks down below the ocean floor; and the sinking involves first a more equable, and soon an increased temperature.

But it is also by and with water that the change takes place, for water is everywhere and at all times circulating through the earth. Entering from the surface and passing down by every crevice present in the substance of every rock, and always tending to produce some alteration, it is impossible to over-estimate its importance. It is certainly by and with water that all essential change must be traced; but let us consider the principal varieties of rocks, one after another, with reference to this point. Some rocks, it is clear, will be more, and more easily, affected by others, and probably in a very different way. Thus, sand or pebbles, with occasional thin beds of marl, will be little altered, and indeed such rocks, when found in the earth, are often hardly changed from their original state. They are neither more compact nor of different texture. Sometimes, no doubt, they are converted into stone, the sand particles being cemented by carbonate of lime, silica, or oxide of iron, but these have all been unmistakably brought in and deposited by water. Sometimes, parts are unchanged and other parts converted into crystalline quartz rock, but there is no mark of heat. Sometimes, on the marly films are crystals of marl, occupying places once occupied by crystals of salt. The marl has been carried in by water to replace the salt crystals dissolved by water. Scarcely any organic remains are preserved in such material now, and there is not much indication of life in the older examples, but footprints of animals, worm casts, &c., prove that life was present. Crevices in the sand rock are filled up with crystalline quartz, certainly of water origin.

Limestones are more varied and richer. Deposited as mud, or coral, or shell sand, the particles are cemented by carbonate of lime. Sometimes the whole mass is compact and crystalline, sometimes parts are crystalline, sometimes the whole is semi-crystalline. The shells are changed; they preserve their form; they sometimes retain part of their original structure, and sometimes they are full of calc spar; or the shells are gone, and their place is occupied by casts, also of carbonate of lime, or perhaps of iron oxide. The whole mass is uniformly tinted with iron oxide: or the iron is collected into belts, and these are often rich enough to be exceedingly valuable as iron ore. The rich ores recently discovered and now chiefly used in the north of England are of this kind. Any foreign substances once mixed up with the limestone mud are now collected and separated in veins or crevices. Large cavities and empty spaces are common in the mass, and these are filled partly with broken fragments of the same limestone, partly with valuable ores of lead and zinc. The whole series of operations, thus changing the limestone mud into important limestone rocks with mineral veins, is the work of currents of water. Water has compacted the loose particles; water has opened large cavities; water has filled them with quartz and other crystals; and water has carried in the metals. A little heat would have caused other combinations.

The case of clays is not different. Very frequently retaining all their essential features as aqueous rocks:—the marks of bedding still easily seen:—the remains of plants, shells. teeth, and bones, still common:—it is not rare to find some of these clays converted into shales, and it is yet more usual to find them alternating with calcareous or irony bands, as already alluded to. These are not unusually collected round some group of fossils, acting perhaps as a disposing cause for the separation. The slates are yet more striking illustrations of change; and in them also occasionally shells and other fossils, little altered, indicate a water origin. Water currents, acting under enormous pressure, have so far altered clays that they have become slates. But the veins, or cracks and crevices that abound in slates, are filled with quartz in a crystalline state. These are often full of holes, and within them sometimes iron pyrites, sometimes valuable ores of copper, make their appearance. But in the deposits of ore there is still no appearance that is not more readily explained by the action of water than by fusion. Currents of heated water—electric currents passing through the earth in definite courses —these would seem to have been the agencies in producing all the transformation and metamorphosis of the richest metalliferous rocks of Cornwall and other countries, where mining is carried on in slate.

When we examine such rocks as granite and the large group of compounds of which it is the type, we enter on more doubtful ground, and must proceed more cautiously. The texture and appearance of granite are, it is true, unlike those of lavas, ancient or modern, but mere external characters have not much value. The microscope, however, shows that a very large class of rocks, of which granite is one, have been formed in contact with water, for water in a fluid state is actually mixed up with them, and is contained within the separate crystals of which they are constructed. That granites, syenites, and greenstones, with the host of rocks of the same or nearly the same general character, have been formed with water, there can therefore be no doubt; but it is uncertain what temperature has been needed to produce them.

The reader may be prepared to ask how it is that chemical changes so energetic, transformations and replacements so complete, and metamorphoses on a scale so gigantic are consistent with the ordinary state of apparent tranquillity of the interior of the earth. The rumblings of earthquakes, though not infrequent, are limited to very small areas; the eruptions of volcanoes are even more limited, and are altogether exceptional phenomena, occurring on a large scale in the same district only once or twice in a century. But the changes we speak of must be incessant, and their amount very large. Their effects are everywhere.

We reply that the apparent repose of the earth is not real. The giant oak standing firmly rooted in the earth, and for centuries unmoved by the fiercest storm, owes its apparent uniformity of condition to changes incessantly going on within, and to ceaseless currents of sap that circulate through its whole tissue—but it only lives, and is strong, because of the continual change and replacement that we call life. So, also, our great old globe itself has its life, its fluids circulating throughout, removing, replacing, modifying, and renewing. Everything in nature is in perpetual circulation, and water passing everywhere is the circulating medium. It is the earth's blood, preserving life, replacing the old and worn-out material by new material, separating that which has performed its work, putting it in the way of entering into new combinations, and enabling it to come in once more as a useful element.

But there is something besides, for the word life has a different and a higher meaning. Vitality requires not only a circulating fluid, but a certain energy, which in the animal we connect with the nervous system. Those currents of earth-magnetism, obtained in some mysterious way from the sun, and passing from pole to pole of the earth, both above and within the surface:—recognised in the air by one kind of phenomena, and now well recognised in the substance of the earth by their effects on the telegraph wire:—those electric forces induced by and governing chemical change, such as the passage of currents of water through different minerals cannot fail to produce; all these are the representatives of nervous energy in the earth, while all, so far as we know, are strictly superficial phenomena. Lastly, there is vital heat, represented in the earth also by the higher and equable temperature at moderate depths.

Aqueous action producing stratification, and metamorphism altering strata, are thus the great facts of geology. Every fragment of limestone, sandstone, and clay, or shale, that enters into the composition of the rocks of the earth has been first water-formed, and is now more or less metamorphosed; every fossil that is found bedded in rocks is likewise changed, and shows metamorphism. It is not only the granites and other crystalline rocks that have been so much altered that their original texture and history are lost sight of; but all other rocks in all countries tell the same tale. There are proofs of this, and illustrations of the mode of change everywhere, and the great agency employed has certainly, in most cases, been altogether unconnected with heat and igneous fusion. The very oldest rocks, even those lowest in the series, all, by their nature, structure, and composition, presume the existence of other rocks still older, and all, without exception, have been derived by the aid of water from the destruction of some of yet greater antiquity. All rocks, without exception, have also been acted upon, and greatly modified in external appearance by the mechanical action of water running over the surface.

Such are the great facts and results of geology, a knowledge of which is necessary to understand the full meaning, and enter into the investigations, of physical geography. The air, earth, and water, and the heat that helps to bring them all into an active and living state, belong to the earth's early history. They are not things of to-day, and they will not cease to act in our time. By connecting the investigations of the physical geographer with those of the geologist, we first learn the full meaning of the phenomena observed by either.

PART THE SECOND.

EARTH.

CHAPTER IV.

LAND.

Of the whole surface of the earth, only one-fourth part, or about 52 millions of square miles,* rises above the uniform level of the water, and forms the land. The rest (145 millions square miles) is covered to a variable but nowhere very considerable depth by water. The surface, both that part covered by and that rising above the water, is very irregular in its form and extension, both horizontal and vertical. This irregularity extends to every detail; and as it cannot be regarded as essential, being rather an accident of the present time than anything more permanent and liable to change by the action of various causes; and as, moreover, the exact physical configuration of the globe influences, to a very great degree, the conditions of all living things upon it, the subject is one of no small importance. When we investigate the structure of the rocks that make up the present land, and discover that almost all have been formed under water and with water; that all have been exposed to great changes in the interior of the earth, involving a subsidence from time to time far below the present water level; —it is clear that in time to come it may happen, as in times past it has happened, that what is now land may sink down and the present sea bottom may be raised into land; so that what is now continent may become a group of islands, or be buried entirely beneath the waves. On the other hand, other continents or islands may rise up from the lowest depths of the largest oceans to replace those that are lost. In a work devoted to physical geography, it is the configuration of to-day, and not that of an earlier period of the earth's history, that we have to consider; but it is impossible to understand this without looking somewhat widely at the history of the earth's crust. This requisite outline will be found in the preliminary chapter on the succession of rocks.

---

* In this chapter, and throughout the volume, it has been thought advisable to give the measurements in British statute miles, and not in geographical miles of sixty to a degree. The British statute mile contains 1,760 yards, or 5,280 feet. The geographical mile contains 6,086 feet 9 inches, nearly.

The land is collected into three compact masses, and a number of groups of small masses. The former are the continents, the latter islands. One of the three principal masses, that including the three great continents of the old world, Europe, Asia and Africa, is very much the largest; the next in dimensions, including North and South America, is also very large, but differs from the greater continent in almost all respects; the third, Australia, is not only very much smaller, but again different from either. Of the islands the same may be said. They are of all dimensions, some being nearly 1,000 miles in length and others mere points of bare rock. They are grouped in all conceivable ways:—they attain all possible elevations:—they are constructed of all varieties of material. So again with regard to position. A large part of the land is grouped within one hemisphere, so that not more than one twenty-seventh part has land opposed to it in the opposite hemisphere. Thus, if a person stationed vertically over the town of Falmouth, in England, could see half the globe, he would see more than 49 out of the 51 millions of square miles of land, or about an equal surface of land and water. If, however, he were perched equally high above New Zealand, he would see 96½ millions of square miles of water, and less than two millions of square miles of land.*

It is impossible not to be struck with a difference so striking. One cannot but enquire whether there is any known reason for this singular irregularity of distribution, and whether results of importance in reference to climate, and the nature of the inhabitants, do not necessarily exist. Such enquiries inevitably suggest themselves, but to answer them, needs an extended and accurate knowledge of physical geography in all its branches.

---

* Definite reasons have been assigned, based on mathematical grounds, for this singular peculiarity of distribution. They will be discussed presently.

The following general statement of figures in reference to this subject may be useful to the reader. The figures represent millions of square miles.

Total area of water	145	197
Do. land	52	
Water north of the equator	59	197
Land do.	39	
Water south of the equator	86	
Land do.	13	
Total area of Asia	18	33½
Do. Europe	3½	
Do. Africa	12	
Total area of North America	8	15
Do. South America	7	
Total area of Australia and islands		3½

It will be observed, that the hemisphere containing the greatest amount of land is not strictly the northern hemisphere, nor can it be said to have any reference to east or west. Neither is it central with regard to the principal masses of land. It includes a large part of the Atlantic Ocean; and as that ocean is shallower than the Pacific, the protuberance of solid matter in one direction is even more marked than might at first appear. If we could see the solid surface of the earth deprived of its watery covering, the irregularity in form produced by this protuberance would be very marked. It is connected also with the earth's history; for all these portions now protuberant have, beyond all doubt, been buried beneath the sea for ages, before being thrust out in the manner we now see; and we cannot tell how far or how long the present bottom of the sea has been exposed to the air, since we have no means of examining its geological structure. Certainly, the lands not belonging to the great protuberance seem to have been less exposed to frequent elevation and depression than those of the other parts of the earth.

An ingenious attempt has been made to solve this problem of the arrangement of the land and water, by supposing the specific gravity of the rocks in the water hemisphere to be greater than in the other. This is assumed to be due to the presence of a much larger quantity of metalliferous and other heavy mineral in those districts, and to a more cavernous and open structure in the rest, and to the greater abundance of light minerals. Mr. James Yates has imagined that the centre of gravity of the earth is not coincident with the centre of magnitude without the protuberance of water on one side. And he concludes, that the earth's surface and the inequality of land in two opposite hemispheres are permanent, and have been connected with the earth's adaptation to life from the beginning.*

By the protuberance of the land the oceans are determined, for they being water, cover those portions of the general surface which are below a certain level, or within a certain distance from the earth's centre. It has been estimated that the elevations of the land are parallelled in some measure by the depressions in the sea; and that as the loftiest mountains are for the most part situated within the larger tracts of land, so the greatest depths are in the larger and more open oceans. At any rate, the actual elevations and depressions are very small indeed compared with the earth's radius. If we estimate the total distance, from the lowest depths of the ocean to the summit of the highest peak of land at 14 miles, and this is probably beyond the truth, the ratio of this to the earth's radius—about 4,000 miles—is a little more than one three-hundredth part. On a globe of the largest size (36 in. diameter) this would correspond to a thickness of less than one-sixteenth of an inch. The depressions and elevations are also small compared with the distances between them. From the highest point in the Andes to the deepest parts of the Pacific, there cannot be a less horizontal distance than 1,000 miles. From the lofty Himalayas to the Indian Ocean there is a much greater distance. The average slope cannot, therefore, amount to one foot in a hundred; so that in fact, on a large scale, there is no considerable average slope on any part of the surface. This, of course, does not prevent the existence of precipitous cliffs and steep mountain sides, either on land or beneath the sea.

Although the vertical irregularities of the land are small compared with the dimensions of the globe, we must not conceal the fact that they are locally great and are of infinite importance in modifying climate. In reference to the first point, it must be remembered that the surface of the solid earth, whether above or below the water, does not consist of even and regular slopes. There are large districts or belts of extremely elevated land, and large troughs greatly depressed. There are extensive plateaux or plains, at great elevation, and others at a lower elevation,—there are terraces very near the sea level, some at a moderate depth, and others at great depth beneath the sea. There are steep abrupt cliffs, both within the land, at the border of land and ocean, and separating submarine terraces. There are deep abrupt gorges and ravines at all levels, and the mountain chains with these deep gorges are not all lofty, nor are they all even dry land. Such phenomena belong to the earth's form, and are essential to it. And there are very wide depressions or valleys, also at various levels, and quite unlike the deep ravines. All these form what geographers call "the physical features of the earth:" they belong to it now, and they are connected with its history.

---

* *Ed. New Phil. Journ.* (n. s.) October, 1862.

The form of the land, and the relative quantity of the land above the sea, are evidently independent of the absolute quantity of water in the ocean; but the land, as seen, and as the habitation of land animals and plants, is dependent on its extent, on its position and on its elevation, for it is strictly limited by the line of contact of the water. Its form and content consist of the area contained above this line, whether above the sea level or not. It is liable to change, according to various circumstances, and to a very large extent. Thus, if we could imagine the great mountains of the earth to be pared away, and thrown into the ocean, the water would rise above its present level in proportion to the mass thrown in. It would spread over the low lands and thus diminish the area of the land, and as the quantity of land is not large, this might go on till no land was left. On the contrary, if the mountain chains of the earth were greatly elevated, and the low plains lifted up to become lofty plateaux, the spaces formerly occupied by this solid matter must be occupied by water, and the level of the water would sink, laying bare and converting into land shallows and banks now near the surface, and belonging to the region of ocean.

It is important to bear in mind these hypothetical, but very possible, changes, if we would understand clearly the physical condition of our globe.

The line of coast by which sea and land are limited is a physical fact of very considerable interest. A flowing and continuous line, little broken by inlets, bays, gulfs, and inland seas, is eminently ill adapted for that water communication that is most valuable for commerce. Thus lands, whose shores are little broken, are almost inevitably reduced to depend on their own productions, and may not hope to enjoy important traffic with the rest of the world. So, again, oceans with such coasts are not the seas where commerce is most active, for the absence of good harbours greatly interferes with traffic, and prevents a country from having much commerce or intercourse with foreign nations.

We have described the land as grouped into continents and islands—the connected and the disconnected lands. This division supposes land to be made up of the lofty and the low, of broken and level portions connected together, the low-level plains occupying the inter-spaces between the high plains and mountain peaks. And it is evident that every extensive tract is so made up, and that it is only exceptionally that even small islands do not exhibit something of this irregular surface. Thus islands are only portions of submerged continents, and the continents are only portions of the sea bottom elevated above the sea with the peaks and ridges. Generally we shall find that peaks and ridges lay bare metamorphosed rocks, while the plateaux and low plains present strata of deposition. There is much mutual relation, and the geographical terms are duly appreciated only when their geological meaning is understood.

The lands on the earth are differently grouped. The great continent ranges from north-east to south-west. It hangs round the arctic circle, and is almost connected by land with the northern extremity of the American continent. It cost many a valuable life, and required the energetic efforts of the bravest and boldest seamen for half a century to discover the fact, that there is a water channel between them. From east to west, with a variable breadth which reaches to 140° of longitude, and with an area of 33½ millions of square miles, an almost compact mass of land extends to about the 20th parallel of north latitude, and thence dies away towards the south. This mass is fringed with islands on the east, west, and south. But though not improperly described as compact in the absence of any great body of ocean reaching the interior and central part of this land, there are yet on all sides many large, and innumerable smaller, breaks and inlets. The whole, also, exhibits certain peculiarities of form that seem to be significant. Thus the pyramidal termination towards the south of all parts of this land is remarkable. The great continent takes the form of a huge hand stretching with open fingers towards the south. This is seen, on a large scale, in the form of Africa, India, Arabia, Malacca, China, and Kamtchatka. On a smaller scale, and in detail, it is recognised in the peninsulas of Scandinavia, of Spain, of Italy, and of Greece. And this form is not confined to the great continent. It prevails also in America. Both the great divisions of America exhibit it in their general configuration. The northern division of the American continent shows it more strikingly in detail than the southern. Greenland and the extremity of Russian America, California, and Florida, are all striking examples. The American differs from the great continent by the principal direction or axis of its lands. This axis is north and south, or more strictly NNW. to SSE. The length in this direction is nearly that of the great continent from east to west, but its width is small, in few places exceeding one-fifth of the length. The length may be stated, in general terms, as about 9,000 miles.

The difference between the two masses of land in respect of the direction of extension is not more striking than it is influential. It affects everything—climate above all. It affects the movements of the waters of the ocean, and modifies the winds that blow over the whole surface of the earth. It is one of the great facts in nature, and above all it must be remembered, that though existing now, there is no reason to suppose that it has always existed, or will continue. Connected with it are the different directions of the mountain chains, the nature and extension of the rivers, and the details of the form of the coast.

We must now consider the details of the coast lines. The great continent is subdivided into three parts—Europe, Asia, and Africa. Of these Europe and Asia are so naturally connected that the division is arbitrary and political rather than geographical and physical. Still, as it has been the universal custom of civilized man for all ages to consider Europe as distinct from Asia, we must bow to this decision, and describe them separately, so far as that is possible. Of the two, Europe is very much the smaller, but has been for many centuries the part of the world where man has most completely subjugated nature. In earlier times a corner of Africa, and still earlier, and for a long period, Asia was pre-eminent in this respect. It is hard to say where civilisation began.

Of all the continents (using the term in its limited and popular sense as convenient divisions of the great continent) Europe has the most varied outline. Its principal mass, which contains about 3¾ millions of square miles, has a coast outline of not less than 20,000 miles. The same area might be contained within a circuit of less than 6,000 miles. For every 187 square miles of surface it has a mile of coast, and in this it will be seen to contrast remarkably with other lands. Its principal mass is deeply intersected in the north by numerous inlets from the Arctic Ocean, and on the west by the Baltic Sea and the Bay of Biscay, in addition to numerous small inlets. Its Mediterranean coast is still more complicated, and peninsulas and nearly detached promontories there repeat, almost to infinity, the phenomena of articulation and indentation of the coast, so characteristic of the whole continent.

Asia, regarded as a division of the land, is an extension of Europe to the east, and, like Europe, is washed by the ocean on three sides only. The northern coast is much indented, but not by large and important gulfs and inlets. On the eastern and southern coasts there are peninsulas and promontories on the grandest scale. From Kamtchatka round the whole coast to Arabia there is a succession of these, including amongst them India, Malacca, and Cochin China. In spite, however, of the great magnitude of these indentations, and the number of smaller inlets that it would be tedious to mention, there is yet an enormous preponderance of land far removed from the sea. With an area of 19 millions of square miles there are 36,000 miles of coast, averaging one mile of coast to 528 square miles of surface, or only one-third as much as in the case of Europe. Regarding Asia and Europe as one tract of land, we have an area of nearly 23 millions of square miles, and a length of coast of 56,000 miles, or one mile of coast to 410 square miles of area.

Africa is remarkable for the simplicity of its outline and the absence of deep indentations in its coast. Surrounded by the sea, except at the very narrow isthmus of Suez, it is almost without a peninsula or inlet of any kind. Its area is nearly twelve millions of square miles, but it has only about 16,250 miles of coast, or 788 square miles of surface for each mile of coast. This proportion well represents the peculiar and hopeless condition of Africa in reference to that inter-communication with other countries, which most surely and rapidly ensures civilisation and the general improvement of the human race. We shall see hereafter that in regard to internal communication the old continents exist under similar conditions—those in which communication is easiest being precisely those in which civilisation has made most rapid progress.

Comparing the old world with the new, the great continent with the two Americas, we find that each of the divisions of the new world is superior in length of coast line to Asia, though inferior to Europe. North America, with an area of nearly 7½ millions of square miles, has a shore line of 28,000 miles, or an average of one mile of coast to 266 square miles of area. South America, with a somewhat smaller area, (about seven millions of square miles) has less than 16,000 miles of shore line, or an average of one mile of coast to 440 square miles of area. The two divisions together, with 14½ millions of square miles, have a shore line of 44,000 miles, or one mile of coast to every 330 square miles. Lastly, in Australia we have a territory of about three millions of square miles, with a coast line of about 8,800 miles, being one mile of coast to every 340 square miles of country.

The general nature of the lands whose coasts are thus characterised may now be discussed, with the preliminary remark, that a broken line of coast is more usually rocky and bold than one where the indentations are few and small. Within a certain distance of most shores there is some cliff or rapid elevation, varying according to the nature of the soil and rock, and the action of the sea upon it; but the most remarkable fjords and inlets are to be found where the line of coast is longest in proportion to the area. Steep, lofty, and irregular cliffs frown upon the sea along the western shores of Europe, and a large part of the Mediterranean. Similar cliffs are seen elsewhere, where the coast line is greatly extended. Within the crevices and interspaces of these cliffs are found sheltered harbours, well adapted for shipping, and in the lands thus surrounded and defended are the chief marts of commerce.

The land of the northern part of the great continent includes all varieties of surface. A central axis runs through the whole, from the Atlantic to the Pacific, and the greater part of this axis consists of ridges of mountain land, more or less lofty. In parts the mountains form parallel or divergent ranges, separated by very wide intervals of lofty plains. Such plains are found in the Iberian peninsula in Europe, and in the vast plains north of the Himalayan chain in Asia. Elsewhere we find broken, picturesque, and hilly country, not much connected with, or dependent on, the mountains, but greatly affecting the physical features of the country. Among the plains are the steppes of western and northern Asia, the great plains of Russia, and the numerous plains of moderate elevation in northern Europe. Connected with them are lower plains to the north, both in Europe and Asia. Everywhere we find the land descending rapidly to wide flat tracts to the north of the great chain, while to the south it descends in many places to high terraces and plateaux, of which India, Arabia, and the Spanish peninsula, are examples. Between and amongst all are the beds of rivers, many of them now large and important, but almost all bearing marks of having been formerly much larger and more influential. These are the valleys which usually open out from gorges in the mountain chains. Generally the river valleys are at first at right angles to the mountains. Afterwards they not unfrequently alter their direction, and run for long distances parallel to the axis of elevation. Here and there they are seen to cross abruptly the lofty chains through deep cuts. The rivers of Europe and Asia are both numerous and large, but few of them are of the nature of torrents, as they run, for the most part, over gentle slopes. For this reason there are few great waterfalls. The lakes, or accumulations of fresh water in Europe, are not remarkable for their dimensions, although often so placed as to afford the most enchanting views of mountain scenery.

The African, or southern portion of the great continent, differs remarkably from the northern division. It has no continuous or well-marked mountain axis, but in place of this an encircling chain of high table land, enclosing a vast area of the nature of a partially dried-up swamp. The northern part of this chain connects itself with the great mountain system of the old world ; but there is a broad, low, unwatered valley—the Sahara, or great desert of geographers—between this northern elevated tract and the south. The existence of a mountain chain, or at least of elevated high land on or near the line of the equator, shutting in the great central swamp, is probable, and has been asserted on the authority of natives and Arab merchants. It was believed to exist by the late Captain Speke, and its western extension to the Guinea coast has been asserted by many African travellers. Du Chaillu believed that he travelled through some part of it, but his evidence was insufficient for want of accurate observations of latitude and longitude. Africa is watered by some of the largest rivers on the globe. Three at least of its streams are remarkable for their great length of course, but except in the case of the Nile they bear but a small tribute of waters to the ocean Perhaps the most remarkable feature of African physical geography is to be found in its lakes. These vast sheets or ponds appear to exist at intervals among the high plateaux that surround and enclose the interior of the continent. They are numerous as already known, and probably there are many others not yet visited and described. They communicate imperfectly, sometimes by rivers of importance, and two of them at least are head waters of the Nile. The rivers of Africa are not less remarkable than the lakes,—they circulate round and through the interior plains and plateaux, and, except in the case of the Nile, they do not present any important deltas where they enter the sea.

The American continent differs exceedingly from the great continent. Its mountain axis is nearly at right angles to that of the old world, and it is placed close to the western side of the land. Thus, on one side there is an immediate and rapid descent to the sea, and on the other a succession of vast terraces, watered by the largest rivers in the world. In the north the condition is somewhat varied by a subordinate, but not unimportant mountain range, near the east coast; and this exists also in Brazil, in South America. There is in North America a chain of gigantic lakes connected together, all discharging their surplus waters by one great river. In the rest of the country there are no very large lakes; but among the Andes are some at an extreme elevation.

Australia is a continent singularly different in its physical features from any of the other large tracts of land on the earth. With few mountains and rivers—the latter either running part of their course underground or disappearing altogether—with a vegetation and animal inhabitants altogether exceptional, it is yet found tolerably well adapted to European habits, and is in the way to be peopled from its antipodes. It has no mountain axis, properly so called, and no circlet of mountains, no permanent lakes, and hardly any important rivers. Much of the interior is level. Large areas are considerably above the sea, though very level; and there are no great contrasts of form as in the other lands, except along the eastern coast. Although once thought inaccessible, and, owing to the absence of permanent streams, almost uninhabitable by civilised man, the recent explorations and the successful traverses that have been made across the country from sea to sea, tend to prove that the difficulties of reaching and cultivating the interior have been exaggerated; and that settlements will gradually extend backwards, especially from the south and north, till they meet in the almost unknown centre. At any rate, there are no lofty mountains, no large lakes, and no interruptions of desert land to interfere with this result.

The islands, as we have already pointed out, are but the plateaux, ridges, and summits of submerged land; or rather of that part of the solid surface of the earth of which all the lower parts are below the present level of the sea, Those that form groups, fringing the great tracts of land, would seem to belong to and form part of such land. Those that rise out of the open sea, far from the land, form groups more or less connected, showing the position of the submarine high lands, and are suggestive in the highest degree of the structure of part of the earth otherwise concealed from us, and buried beneath the ocean floor. Some of them are volcanic, or are connected with burning mountains of ancient or modern times. Others are organic, having been formed directly and evidently by the accumulation of matter by living beings. Of these, the coral islands are the most remarkable and the most suggestive in reference to the history of the earth.

Those islands which, from their form, mode of grouping, and position, seem to belong to former or existing continents, are the largest in dimensions, the most easily understood, and the most familiar. Among them, we may first allude to the islands of the Indian Archipelago.

The Indian Archipelago is an extensive group of islands dividing the Indian Ocean from the Pacific, and connecting south-eastern Asia with Australia. The great Malay peninsula, though joined to the main land, is really, for the purposes of physical geography, a part of this group of land. The vastness of the islands and their number, the extent of vegetable and animal life, and the special characteristics of this land, deserve separate notice. The whole area of the Archipelago is nearly equal to that of Europe; and two of the islands, Borneo and New Guinea, are the largest on the globe. After these come Sumatra (as large as Great Britain), and Luçon and Celebes, each of which is larger than Ireland. There are eighteen islands as large as Jamaica, more than a hundred about the size of the Isle of Wight, and many thousands smaller.

A long series of groups of islands, beginning south of New Zealand, and including the islands known by that name, New Caledonia, the New Hebrides, and the Solomon islands, connects with New Guinea, and together form part of a great tract, now submerged, but not long ago above the waves. It is not merely from the examination of a globe or map that these analogies are recognised. The distribution of animals and plants, and the nature of the intervening channels, are generally found to agree in pointing out which lands are connected and which are disconnected; but there is much yet to be learnt before the grand outlines of those parts of the earth's surface that are so largely covered by sea can be satisfactorily made out. The reader is referred to the chapter on oceans, and to that on volcanoes, for further indications of these great outlines. Further out in the Pacific there is another long and important chain of islands, almost entirely crowned with the habitations and skeletons of the coral animal. All these seem to belong to land once above the sea, and now sunk below it. It is only the work of the coral animal that now marks its existence. The Caroline Archipelago, and a continuous series of islands extending to the Low Archipelago, are indications of an irregular line ranging from north-west to south-east, and crossing the equator, on which, for several thousand miles, there are marks of uniform and continued depression. In all the islands and reefs, and their number is utterly incalculable, belonging to this wide and extended tract of ocean, there is evidence, from the nature and construction of the coral with which they are capped, that they were formerly much above their present level, and in many cases the difference of level is very large indeed. Although, therefore, the islands are small, the phenomena represented by them are on the very grandest scale.

In the Indian Ocean there is another series of island groups, including the Laccadives, the Maldives, and the Chagos Archipelago, connecting with Madagascar by the Sechelle islands to the north, and the Mauritius and Bourbon on the south. These are partly coralline and depressed, but nearer Madagascar they have been elevated. They are parallel to, and form part of, an island system connecting Hindustan with Africa. The main chain of the West India islands in the Gulf of Mexico and the Caribbean Sea, the ranges of islands on the eastern shores of North America, and the islands on the opposite shores of the Atlantic, our own British islands being amongst them, are of the same nature. They are practically the summits of elevated ground, separated from the main land of Europe by channels now covered with water, but forming the natural terminations in each case of their respective continents. Beyond them there are deep and sudden depressions, or cliffs, conducting to lower terraces, disconnected with the continents.

Thus, then, these island groups are either parts of present continents or the last remains of former continents, and they are important, if only as indications of the former history of our globe. They are valuable, however, not only from their position, but still more by the forms of life they expose to our view. Thus, while some of them contain nothing more than a selection of the species common now in the adjacent continents, others are altogether independent in this respect. Whatever may be the laws of distribution of life, it cannot be doubted that so great a difference as is here found belongs to the history of the globe. Either the circumstances have changed to an enormous extent, or a very long time must have elapsed since the former connection existed.

When we contemplate the physical features of the earth on a large scale, many matters that, in a single instance, might seem unimportant, become suggestive and interesting, owing to their frequent and systematic repetition. Among these may be named the general directions of the longer and shorter slopes of mountain sides. Almost all elevations of any considerable extent—all true mountain systems—have one side steeper than the other. The whole chain of the Alps slopes gently to the north and falls rapidly to the south. The great Himalayan chain falls by slow degrees and numerous steps towards the frozen sea, but drops down almost vertically towards the plains of India and the valley of the Ganges. And so in America, the chain of the Rocky Mountains and that of the Andes are exceedingly precipitous towards the Pacific, but pass by gentle slopes and vast plains towards the Atlantic. In other words, in the old world the long slopes are towards the north and the short slopes towards the south. In the new world the gentle slopes are towards the east, the precipitous slopes towards the west. It is also the case, for the most part, though by no means without exception, that the highest elevations are not very far from the equator. This is the more remarkable, since there is no approach to an equatorial belt of land, still less of high land, nor are the culminating points in the two hemispheres within the same tropic. It seems probable that the character of the land is continued beneath the ocean, and that the Pacific and Indian Oceans are deeper and more abrupt than the Atlantic.

The characteristic of the great mass of land in the old world is rather lofty plains and mountains, than either low plains or valleys, and this, notwithstanding the fact that the traveller may cross the northern part of the old world from the Atlantic to the Pacific, along a distance of 6,000 miles, without encountering a hill more than a few hundred feet in height. Europe is, on the whole, a hilly and mountainous country. Asia contains the loftiest mountain groups of the globe and, also, vast plateaux. Africa has its lofty mountains and elevated plains. Deserts, very little above the sea level, accompany the plateaux, but are small in comparison.

On the other hand, America, notwithstanding the important and lofty chains of the Andes and Rocky Mountains, is really characterised by its plains. The high lands are a fringe of plateaux, and the gigantic valleys, of which those of the Mississippi, the Amazons, and the La Plata are examples, are low plains. It is in America, also, that we find the largest number of great rivers and the largest lakes. Mountains, except in the great chain of the Andes, in Central America and on the west coast of North America. are subordinate, the important cultivation and vegetation of the continent being dependent on the broad, rich, level tracts that reach for thousands of miles in successive terraces, almost unbroken by hills, through a large part of both divisions of America.

Australia, also, is a land of plains, but of unwatered plains. Unlike the American land, we have here no sufficient mountains to produce great rivers, and the form of the country is such that the waters do not drain off by open valleys to the sea. The great islands of the world do not always partake strictly of the character of the land to which they are subordinate, and, were the water absent, we might see very great modifications in the general outline of the continents. Thus, New Guinea is a mountainous island; New Zealand has its axis of very elevated land; and, generally, each principal island of a group is so, because it partakes of a mountain character, rising above the mean level as a mountain peak, not as part of an elevated plateau.

Some such general sketch of the present condition of the earth's surface, and especially of that part which is now above the sea level, is not only interesting in itself, and necessary as an introduction to physical geography, but is the connecting link between physical geography and geology. There has always been, among speculative and imaginative writers on the latter science, an irrepressible desire to discover the whole history of the earth, and to trace the gradual development of our globe from a cloud of burning gas, or, as may still be the condition of many of those nebulous bodies distributed through space, from a state of igneous fluidity. This beginning once assumed, it is supposed that the mass has gradually cooled down, till a thin crust of oxidised material has formed on the surface. The crust, being broken up and re-constructed, is thought to have originated the rocks which have since become converted into the solid masses we are all familiar with. When we would generalise upon the facts concerning the form of land and the changes it has undergone, it seems easier and more natural to assume a marvellous activity and energy in the transformations of former times, than to call in the agency of time to the extent otherwise needed. This is illogical; but almost every geologist has given way to the temptation.

A rigid and minute adherence to the evidence before us will not, however, permit us to go far with these theorists. That the whole of the phenomena of the earth point to great and continuous change in every respect and throughout all time is certain, but they do not point to the beginning. Neither in inorganic nor in organic nature is the beginning placed before us in such a way as to be recognised, nor does it permit us to trace development in any other sense than this, that every part of the system involves change continually, that all changes are mutual, and that the earth and seas have gradually become adapted to more complex organic structures.

At the same time it is by no means in accordance with what we know of the form of land, the nature of rocks, and of life, to deny that the advance to the present condition of things has been by a continuous chain of events. There certainly could not have been, from the beginning, precisely such a distribution of land and mountain as there is now. Generally speaking, the oldest mountain chains do not seem to have been lofty, and it is certain that we cannot now determine which are really the oldest, owing to the removal of so many land marks by subsequent action of air and water. The line of coral islands now sinking in the Pacific and Indian Ocean may once have been parts of the back bone of a continent stretching from the south pole towards the equator, with a protuberance, the counterpart of that which is now in the northern and opposite hemisphere. The Scandinavian chain, now low and almost lost, may once have been the main axis of another continent. On the other hand, it is certain that the Alps, the Himalayans, and the Andes, have all become lofty mountain chains in recent times, and may not belong to the early history of the globe. Thus, the limits of land and water, and the great outlines of both, are not fixed or determinate; they belong to one period, not to all time; and it is unreasonable to expect that they should carry us back to the origin of all things, or give a clue that may enable us to unravel the mystery of that condition of the globe when life did not exist as it now exists in connection with light, air, and water, and when the forces acting upon the earth's surface were not bounded by the same limits of temperature as those that are now recognised.

CHAPTER V.

MOUNTAINS.

MOUNTAINS are among the grandest and most picturesque phenomena of the earth. They also belong in a most important sense to its history, for they have not always existed where they now exist. There have once been mountain chains where now the height of a few islands above the sea is very inconsiderable, and all the highest summits of all the chains of the earth have once been buried beneath a great thickness of deposits and a great depth of water. They are all results of elevation on a grand scale, extending over a wide area, and continued for a very long period. In a sense, though not, perhaps, in the sense once understood, they govern the form of continents, for their direction or axis being that of the elevating force, must correspond in a general way with that of the land around them, and at their feet. Thus it is that they are very permanent, and can hardly be obliterated. Wherever hard crystalline rock, formed at a great depth below the surface, is seen at or above the surface, we may be sure that we have before us the remains of some ancient mountain chain, more or less worn away according to the time that has elapsed since it was first elevated, and now strangely reduced from the goodly pile of accumulations that had grown upon it before its upheaval commenced.

There are but few first-class mountain chains on the earth, and it is probable that this was always the case. The old world and the new, the eastern and the western groups of land, each contains its own. The former is broken and interrupted, the latter almost continuous. But both are recognisable. Besides these there are few mountain chains of considerable magnitude, but the great chains are themselves broken up into numberless smaller ones. An account of the chief of these chains will enable the student to recognise the main outlines of the great skeleton frame-work of the globe The loftiest in some parts are not necessarily the chains of greatest interest, or those which represent the greatest amount of eruptive force, nor is it essential to the continuation of mountain chains that they should always rise above the sea level. The structure, form and features of the elevation above the general surrounding level, is that which constitutes them mountains in the strict sense of the term.

In the larger sense there are only two great mountain systems on the globe, that which crosses the old world from ENE. to WSW., on a line about 9,000 miles in length, and that which runs parallel to the western shores of the new world for 10,000 miles from NNW. to SSE. All existing chains of modern date belong more or less distinctly to one of these two. Many are directly and visibly subordinate. Many others, although legitimate offsets, appear at first to be independent. The African and Australian mountains make the nearest approach towards independence. Let us briefly consider the geographical position of each of the different subdivisions of the principal groups, commencing with that which holds the first place on the continent of Europe. It is one of the three loftiest parts of the system of the old world, and although the least elevated of the three, is not the least impressive.

The Alpine chain includes the highest land in Europe. It extends from France eastwards to the Balkan for a distance of more than 500 miles from west to east, and a breadth gradually widening from 80 miles in its western to as much as 200 miles in its eastern portion. The loftiest part of the chain is near its narrowest part. The highest or culminating peaks are nearly adjacent, though separated by a deep valley. They are Mont Blanc and Monte Rosa. The former is estimated at 15,784 feet, the latter at 15,223 feet. There are many practicable passes, the highest of which, the Adler Pass, is 12,461 feet. Another, the Col du Geant, (11,146 feet) crosses near the western extremity of Mont Blanc. This portion is jagged with numerous peaks, pyramids, and needles, of altered rock. There are in the Alps, besides Mont Blanc and Monte Rosa, at least one hundred detached mountain peaks, upwards of 10,000 feet high, all of which are constantly covered with snow. Few of them are inaccessible. but many are both difficult and dangerous of approach. They are surrounded by and buried in snow. Vast sheets of frozen snow or glaciers come down from the higher valleys into the country below, widening as they descend, and often connecting with others frozen streams, just as the waters of adjacent valleys combine and perform the rest of their downward course together.

Athough inferior in height to some of the great mountain chains of the earth, the Alps afford magnificent and picturesque scenery, and exhibit all the most prominent physical features of lofty mountains. They rise in Switzerland from a plateau of only moderate elevation, and on the south side they shoot up at once to the sky from the plains of Lombardy. There is an extension towards the south and west to the Mediterranean under the name of Maritime Alps. Nothing can be imagined more perfect than the mixture of the wildest and most savage scenery, with the rich pine and other forests, and the numerous feeding grounds or *Alps*, from which the chain has received its name.

The higher Alps which form the western division commence on the Gulf of Genoa and curve round, first by the west, and then to the north, as far as Mont Blanc. Turning to the east and north they run through Switzerland and the Tyrol, terminating in the Great Glockner (12,956 feet). The length of this line is upwards of 400 miles. All of it is lofty, and much of it far above the line of perpetual congelation.

To the east of the Great Glockner the Alps split into two branches, called respectively the Noric and the Carnic Alps. The latter is the principal group. Passing into the Julian Alps it joins the Balkan. It separates the Tyrol and Upper Carinthia from the Venetian states, and is much lower than the western mountains.

The width of the Alpine chain in the highest part is about 100 miles. Further to the east it is wider, gradually increasing to 200 miles, and then again narrowing to the point where it connects with the Balkan. At this point the elevated land is not more than 80 miles in width.

There are few lakes or pools among the Alps themselves, although both to the north and south of the chain, in Switzerland and northern Italy, the lakes are among the most striking characteristics of the scenery. There are also no table lands or plateaux near the higher summits. The higher mountains seem to be to some extent detached, but whether this be due to there being many centres of elevation, or whether it is the result of denudation and natural weathering, acting in a somewhat unusual and extreme manner, we muts not here discuss. It is certain that the Alpine chain consists of numerous mountain masses, often with very little apparent connection geologically; but that these have a certain and intimate relation, and have been elevated by contemporaneous upheavals, there cannot be a doubt. At the same time denudation has played a very important part in all the phenomena of Switzerland and the Tyrol, and there is not a mountain peak, a ravine, or an exposed surface of rock, that does not speak of this in language not to be misunderstood.

The great Pyrenean chain, attaining in Mount Maledetta to the considerable elevation of 11,168 feet, extends from the Mediterranean Sea to the Bay of Biscay, and forms a natural barrier and neutral ground between France and Spain. It is disconnected from the Alps by the plains of Languedoc. The chain rises abruptly from the Mediterranean, but only to a moderate height. The higher mountains soon succeed, and there is no low pass across the whole range. The principal summit is a wavy line, whose mean altitude is 7,000 feet, but this is broken into a vast number of peaks, upwards of twenty of which rise more than 3,000 feet above this average. The greatest breadth of the chain is about 60 miles, and the length is 270 miles. On the French side it is steep, rugged, and serrated, the peaks ascending by successive terraces. On the Spanish side gigantic sloping spurs separated by deep precipitous valleys extend as far as the valley of the Ebro, but the depression on the Spanish side is much less than the rise on the French.

The range of the Pyrenees consists of two parts, having the same general direction. The two divisions form an angle with each other near the head of the Garonne, the eastern portion advancing slightly towards the north. On each side of the principal ridge most of the valleys are transverse, and some of them of considerable length. They are much closed in, and some of them abound with hot mineral springs.

The position of the line of perpetual congelation in the Pyrenees is somewhat doubtful. On the northern side, it has been stated at a little more than 9,200 feet, and on the southern at 8,300. Glaciers are frequent in the vicinity of the loftier peaks, but they do not occupy the deep gorges as in the Alps, and they have not left such marked records of their former extension.

The Pyrenees may be regarded as the western extremity of the great central mountain district, of which the Alps exhibit the loftiest elevations. They correspond in this respect to the Carpathians, the continuation of the Alps towards the east and north, and bounding to the south-west the vast plain of northern Europe. The Pyrenees, however, extend westward beyond the extremity of France, and form the northern boundary line of the Iberian peninsula. In this part they are not so lofty as in the eastern part.

The Carpathian mountains commence at Presburg, in Hungary, and extend at first NNE. for about 100 miles, in a range about 2,000 feet above the sea, rising with sharp acclivities and covered with forest.

From this point the range turns east and continues in that direction for nearly 200 miles. This portion is broader than the others, extending for 20 miles or more, whereas the western part does not average more than 16 miles. The summits are also much loftier and include the most elevated peak of the whole chain. The highest of these belong to the Mount Tatra, an enormous mass of rock extending from west to east for about 50 miles, and nearly 30 miles in the broadest part, from north to south. The average elevation of this mass is estimated at 7,000 feet, but several peaks rise from it above the line of perpetual congelation, the loftiest of them (Ruska Poyano) being estimated at 9,912 feet above the sea. As many as twelve other peaks also rise to the height of 8,000 feet or more, and on one of them is a small glacier. This singular mountain mass is separated from the rest of the Carpathian chain by valleys little more than 2,000 feet above the sea, and therefore nearly 7,000 feet below the Mount Tatra.

East of the Tatra the Carpathians turn towards the south and form a very extensive and broken mountain district between the valleys of the Danube and the Dneister. Towards the west the higher peaks rise to 6,500 feet, but further south and east they are much less important. The Transylvanian mountains form the eastern continuation of the Carpathians, and stretch away towards the swamps at the mouth of the Danube.

The continuation of the Alps on the right bank of the Danube is by the mountains of Dalmatia and the Balkan chain;—the former are sometimes called the Dinaric Alps, and form a spur of the main chain, reaching in Mount Dinara to the height of 5,670 feet, and forming a deeply-indented and desolate tract nearly parallel with the Apennine chain.

The true Balkan range extends from the Adriatic to the Black Sea, in latitude 42°—43° N. The mountains increase in height towards the east, but descend again to the Black Sea. The Tschar Dagh, the highest peak, is estimated at nearly 10,000 feet above the sea, and the whole mountain system is distinguished by craggy summits and steep sides. Many parts of the range are little known, as travelling is everywhere difficult, and the country is often impassable. The higher portion is only traversed by one road, passable by mules and asses.

The Balkan is connected with the Carpathians by low but distinct ridges, which, where the Danube crosses them, shut in and interrupt the passage of that river, forming the well-known gorge of the Iron Gate.

Three continuous chains branch off from the southern ridges of the Balkan, the most easterly running down to Constantinople, forming a rocky though not elevated ridge, difficult to traverse. The middle spur runs for some distance south-east, parallel to the former, but afterwards turns east and meets it. The third, or most westerly, runs through Albania into Greece, terminating at Cape Colonna and forming the Pindus chain. The latter is the most important, and includes a district the most mountainous in Europe.

The highest mountain in Greece is Mount Guioma, an eastern offset of the Pindus chain. It has been estimated at about 8,000 feet above the sea.

The Apennines form a chain of considerable importance, though subordinate to the great European mountain system. Diverging originally from the Alps, they run in a south-easterly direction entirely through Italy for a distance of 650 miles, from the Maritime Alps to the extremity of the Gulf of Tarento, at Cape Leuca. There is a divergent but considerable extension of the chain, commencing south of Naples and running across the Straits of Messina to Sicily. The general character of these mountains is that of a subsidiary range,—they neither present the vertical needles of the Alps, the sharp peaks of the Pyrenees, nor even the long rocky cliffs and escarpments of the Jura; their forms are smooth, rounded, and wavy, and bare rocks are rarely seen except in the highest parts. The most elevated point is nearly in the centre of the chain, a little eastward of Aquila, where Monte Cormo rises to the height of 9,523 feet.

The Scandinavian peninsula includes a very interesting chain, extending through Norway and Sweden from north-east to south-west, in a direction which, if continued, would pass through the main chain of the British islands, and which, being also nearly parallel with the Ural chain, is transverse to the main direction of the Alps. This chain includes what is now called the *Norrska Fjellen* (Norwegian range) and the *Kjölen*, and extends from the south extremity of Norway as far as North Cape, running thus through thirteen degrees of latitude or a distance of more than 900 miles. The southern portion (Norrska Fjellen) occupies 360 miles of this, and is by much the most considerable, both in width and elevation, including more than three-fourths of the southern part of Norway.

The ground in this southern part of the range rises from the sea with a steep ascent to about 300 feet. It attains an elevation of 1,000 feet in about 20 miles. Further north, the ground rises to 2,000 feet; and then at Bygle Fjeld the true mountain mass may be said to commence, rising to 4,500 feet, and retaining that altitude for more than 100 miles as an elevated mountain plateau. Out of this project the loftier peaks, reaching an elevation of 8,102 feet in Snae Hatten, a part of the great mountain called Dovre Fjeld. There is a vast number of other considerable elevations, and many hundred square miles of perpetual snow and ice.

Beyond the Dovre Fjeld the mountains called Kjölen commence, and form a continuous ridge to the north-east, having a breadth of about 25 miles, rarely rising into elevated peaks, but exhibiting at intervals isolated summits covered with snow. The eastern declivity is not very rapid, but the western is exceedingly steep and broken, descending upwards of 4,000 feet to the sea in a distance of 10 or 12 miles. Further north the mountains increase in altitude, and occupy a greater breadth, the summits reaching upwards of 6,000 feet within the polar circle, where the snow line on the western declivity is as low as 2,800 feet. Beyond 68°

N. latitude the ground sinks occasionally below the snow line, but presents at intervals many elevations varying in amount, though gradually lowering till they are lost in the sea, and only appearing at intervals in islands beyond the northern extremity of the main land. On the whole nearly 4,000 square miles of this mountain system are above the limits of perpetual snow. The other mountain systems of Europe are of inconsiderable altitude, and only local importance. The most interesting are the mountains of the British islands, including (*a*) the Scotch group rising in Ben Cruachen to nearly 5,000 feet, and Ben Nevis (4,406 feet); (*b*) that of Wales, of which Snowdon (3,590 feet) is the culminating point; and (*c*) that of Ireland, where the loftiest summit, Curran Tuhol, is 3,405 feet.

It is probable that these mountain systems are connected with the great Scandinavian system, with which, as we have observed, they are parallel.

In addition to these the mountain districts of the south and east of France (the Cevennes and the Vosges) and of central Germany (the Fichtelgebirge, the Hartz, the Erzgebirge, the Böhmerwald, &c.) are of local interest and importance, but must be regarded as outlying portions of the great mountain range.

The Iberian peninsula is remarkable as containing several outlying mountain masses rising out of lofty plateaux. The Sierra Nevada is the loftiest of these. It is a small and narrow mountain mass, but rises in Muley Hacen to the extreme elevation of 11,664 feet. There is another peak not much less lofty, and the Sierra is continued along the south coast of Spain to Gibraltar. The Sierra Morena, much less lofty, has its axis parallel to that of the Sierra Nevada, and is some distance to the north. The Sierras called Estrella, Guadarama, and Cuenca, lie between the Sierra Nevada and the Pyrenean chain.

Passing now once more to the east, beyond the Carpathians and the Balkan, and traceable only at intervals, we come to high mountain land on the south of the Crimea. The same chain is continued across from the Black Sea to the Caspian by the Caucasian chain. Towards the north we have the Ural mountains, which branch at a right angle from the mountain axis of the old world. The Ural is a narrow mural range, whose greatest altitude does not exceed 6,800 feet. It hardly anywhere offers the usual characteristics of mountain systems.

It presents, however, steep ascents, precipices, and transverse gorges. The tract is to a great extent inaccessible, as it is covered with vast and impenetrable forests and deep morasses.

The Urals range in all for 1,250 miles. The southern portion reaches to about 55° 30′ N. latitude, and consists chiefly of the table land of Sakmara, terminating in the Irendik range and the Ural-Tau. The central portion scarcely exhibits anything more than a wide swelling ridge, and reaches to 58° N. latitude. The northern Ural is more considerable, jagged mountain peaks rising to the height of from 5,000 to 7,000 feet above the sea, and presenting bare rocks and very extensive swamps.

The Ural is more precipitous, or at least slopes less gradually on the eastern than on the western side, and the northern portion is scarcely covered. These mountains are throughout remarkable for their rich deposits of gold and malachite (green carbonate of copper).

The last of the European mountain systems which require notice here is the Caucasus, and separating Europe from Asia. It extends between the Black and Caspian Seas. This chain is parallel, or nearly so, to the Antitaurus and Taurus ranges, and forms with them an important link, which connects the mountain system of the Alps with that of Central Asia. The Antitaurus on the north and the Taurus chain on the south intervene between the Caspian and Black Seas and the Mediterranean.

The Caucasus ranges from WNW. to ESE. for a distance of about 700 miles, having a width which varies between 60 and 120 miles. Some of the detached peaks rise to even more than Alpine elevations, the highest summit (Elburz) being estimated at 17,800 feet, and many peaks rising far above the snow line, which is here between 10,000 and 11,000 feet. Besides the main chain, which is sometimes obscurely indicated, there are numerous offsets containing mountains of great height, while the loftiest of all the mountain peaks is a detached and isolated rocky mass.

It has already been stated that the Taurus and Antitaurus chains complete the link which, with the Caucasus, connects the two great mountain systems of Europe and Asia. These chains (the Taurus and Antitaurus) both commence in the east at or near a very lofty mountain in Armenia

(Mount Argæus), which, being covered by perpetual snow, must have an altitude of upwards of 10,000 feet. The southern chain (the Taurus proper) first proceeds in a southerly direction near the coast of Lycia, and then westwards, to the borders of the Mediterranean, where it seems to run out under the level of that sea, showing itself once more as a detached chain in the elongated island of Crete. The Anti-taurus flanks the table land of Asia Minor on the north side, and connects itself towards the west with the Balkan.

Advancing still towards the east we now pass to the consideration of the high mountain land of Persia, Caubul, and Beloochistan; the converging point of this tract is known as the Hindu-Koosh, but is sometimes called the Indian Caucasus. It is a kind of mountain isthmus uniting the vast and complicated chains of the great Asiatic plateaux to the lofty and important ranges already described.

The Hindu-Koosh consists of several ranges, some of them exceedingly lofty, and expanding to the east towards the Himalayan chain, but converging towards the west. The mountains enclose many long convergent valleys. They successively overtop each other, and the loftiest exhibits its snowy summits at a distance of 150 miles. One of these summits rises to 20,593 feet.

The Himalayan chain is the southernmost and best known of the three great mountain ranges that rise out of the plains of Central Asia. It extends from the Gulf of Tonquin to Cabulistan, a distance of nearly 2,800 miles, and may be conveniently divided into three regions, all characterised by very considerable elevations, but the central rising into the highest mountains on the globe. Of these regions the eastern, in which is Assam, has been the least visited, but it is known to contain many high summits, one of which has been estimated at 25,000 feet.

The great central range of the Himalayas extends from the valley of the Sutlej (long. 77° E.) to Bootan, in long. 88°, for a distance of about 600 miles, and it is about 100 miles across. It appears to consist of mountain masses, not in parallel ridges, but protruding almost irregularly from the central range, and containing between them transverse valleys, so narrow as to be almost ravines. A vast and unnumbered multitude of very lofty peaks rise more than 18,000 feet above the sea, and some of them attain the height of 28,000 feet. They rise in the most singular confusion. A great part of this lofty tract is always covered with snow, and the intervening valleys are scarcely large enough to affect the striking features of the district. Some of them, however, are so far accessible that roads reach by their means to the lower shoulders of the mountains, and there are several lofty mountain passes leading across the chain. The glaciers in some of these valleys are on an exceedingly grand scale.

Although the central axis of the Himalayan chain is massive and irregular in its character, the general structure of the mountain system is simple. Proceeding northwards from the plains of Hindostan, there is first a tract from 10 to 30 miles wide and 1,000 feet above the sea, and this is succeeded by rocky ridges 5,000 and 6,000 feet high, between which and the higher ranges the country is inconceivably fertile. Beyond these rise mountains of from 10,000 to 20,000, flanking the principal range; and lastly the vast central mass appears, projecting its lofty and snow-covered peaks towards the sky.

The mean height of this principal range cannot be estimated at less than 16,000 feet, and is perhaps much more. Near the sources of the Sutlej there are forty peaks, each higher than the highest peak of the Andes, and this part of the chain is so rugged that there is said to be hardly one spot in which a hundred acres of level ground exist between the valley of Nepaul and the Tartar frontier.

The line of perpetual congelation on the Himalayas has been found to be much higher on the northern than on the southern side, reaching in the former to 15,600 feet, while in the latter it stands at 12,800 feet. It is not easy to account satisfactorily for this remarkable fact.

The Himalayans towards the west converge towards the Hindu Koosh. Near this point the range turns northwards, but continues to present very lofty elevations. The valley of Kashmeer (Cashmere), so well known, and described in such glowing colours by those who have visited it after wandering through the bleak country to the north and west, presents a hollow depression of great extent, rarely ruffled even by a passing breeze. Its beauties would seem to have been somewhat exaggerated.

The Altai, as a mountain system, extends from the silver mines of the Snake mountains, and the confluence of the Uba and the Irtysch, to the meridian of Lake Baikal. There is a nominal but no real division into Great and Little Altai, but the system includes (1) the Altai proper, west of the Telezki Lake, and (2) the east and west chains, parallel with each other, and containing the culminating point of the whole, which is about the height of Mount Etna.

These mountains are not connected with the Ural, there being an intervening space of 400 miles, occupied by low, marshy country. There are other wide intervals, throughout which the mountain chain is recognised only at distant intervals. From the banks of the river Irtysch, the main chain of these mountains extends in a serpentine line to the Pacific at the Sea of Okhotsk, a distance of nearly 2,500 miles, and is then continued for another 1,000 miles by the Aldan range, which is a northerly branch of the main chain.

It is probable that there is also a south branch of the chain running far into China, but the jealousy of the Government of that country has hitherto prevented European travellers from determining the point.

This long and important range of mountain country is, throughout most parts of its course, extremely broad, contracting to its narrower limits (150 miles) near the desert of Gobi, but expanding in some places to as much as 1,000 miles. Although, however, extremely important in respect to the other physical characteristics of Central Asia, these mountains are by no means remarkable for their height, a great part of the chain, as far as the 86th meridian, consisting only of a succession of terraces with swelling outline. To the east, this hitherto low ridge expands and splits into three branches, rising near Baikal into considerable but not lofty elevations, capped with snow.

The mean height of the first and most western part of the Altai chain is about 5,000 feet above the sea, and the loftiest summits (between the parallels of 50° and 51°) reach a height of nearly 10,000 feet. But although the elevation is not inconsiderable, the configuration is very peculiar, the mountains being truncated or terminated at their summits. They are in fact little more than level plains of considerable extent, with numerous deep fissures. They do not consist of a series of irregular peaks.

The continuation of the Altai, eastwards, is chiefly by a mountain range, irregular in the form of the summit, but lofty, and covered with snow. Little is known with accuracy, beyond the fact of the extension of the chain. The great intermediate chain of the Thian-Schan extends for 1,400 miles from west to east, being in some places 100 miles in breadth, and rising occasionally above the snow-line. The higher or central portion of the range appears to be about 40 miles in width, and a very large space to a considerable distance from the summit seems occupied by snow and ice. Towards its eastern termination it is less known, and at about the 95th meridian it suddenly terminates. The whole chain is nearly eight times as long, from east to west, as the Pyrenees. It is a volcanic range, and is lofty enough to admit of glaciers. The active volcanoes are 1,500 miles distant from the icy sea to the north, about the same distance from the mouths of the Indus and Ganges to the south, 1,360 miles from the Caspian, and 1,000 miles from the sea of Aral. In its eastern extension the range gives place to the plains of Gobi, which continue for 9½° of longitude, but the mountains re-commence on the other side, and continue almost to the shores of the Pacific, in the somewhat more southerly chain, the In-schan. The heights of the Thian-schan do not seem to have been yet ascertained by direct measurement.

The mountain system of the Kuen-lin, branching from the Hindu-Koosh, runs very regularly to the east in the parallel of 36° N. latitude, reaching completely across Asia. It is volcanic in many parts, and attains in some places the height of 20,000 feet.

Beyond the eastern extremity of the great Himalayan range there is a considerable tract of country in China whose physical geography is little known, but which appears to exhibit a greatly complicated group of mountain chains. The mountains rise in some places to a great altitude (those of Petsha being estimated at 15,000 feet) while a serrated ridge runs northward and joins a branch of the Altai near the 55th parallel of north latitude.

The subordinate mountain ranges of Asia are numerous and considerable, but not sufficiently important to demand here any lengthened description. It will only be necessary to allude very briefly to those of the three great promontories of Arabia, Hindustan, and Birmah. There are distinct chains in some of the islands of the Indian Archipelago, but they do not seem to connect themselves with the mountain axis of the old world.

Arabia consists of a table land enclosed nearly on all sides by ridges of no remarkable elevation; these seem to form low mountain chains, and the principal of them extends from Mount Sinai, on the Red Sea, along the shores of the Mediterranean, across the Taurus range to the Black Sea. The altitudes of the two highest peaks in this range are 8,593 feet, and 7,498 feet respectively, and the mean altitude of the mountains ranging round the peninsula is between 4,000 and 5,000 feet. The Arabian Mountains connect with the lofty group of Abyssinia and the north-east of Africa.

Hindustan contains two principal chains, the Vindhya Mountains on the north of the Deccan, whose mean height is about 3,000 feet, and the western Ghâts, which average between 3,000 and 4,000 feet. The highest summits of this latter range attain an elevation of as much as 8,000 feet. The Ghâts run everywhere close to the coast of India, and the Vindhya range crosses the upper part of the promontory in an ENE. direction.

The singular triangular mass of irregular land, including the Birman Empire, Siam, Cochin China, and Malacca, contains mountain chains which appear to be transverse spurs of the great Himalayan chain, and which enclose table lands. In the western part of the promontory the Aracan Mountains at first form a ridge of rocky elevations of moderate height, rising in latitude 21° 21′ N. to as much as 6,000 feet above the sea, while similar high mountain ranges slope gradually on the east side, having a much sharper incline on the west. These extend for some distance, and occupy the central part of the country, while long spurs project into the Malay peninsula, occupying with their offsets the whole country from one sea to the other, and attaining an elevation of about 3,000 feet. These same mountains are continued through Siam, where they have an elevation of from 5,000 to 6,000 feet, and are very rugged and bold. They are supposed to branch from some of the lofty and snow-covered peaks surrounding the table land of the Chinese province of Yunnun.

The mountain systems of Africa are still imperfectly known, though much information has been obtained concerning them of late years. They include (1) a high range on the east coast, culminating in the north-east extremity of the continent, and connecting the Abyssinian group with the Arabian system. (2) A corresponding chain on the west coast, culminating near the equator, and supposed to extend thence into the interior. (3) The Atlas chain fringing the shores of the Mediterranean, and forming the southern part of the western division of the great chain crossing the eastern continent. (4) The South African range on the eastern side of the continent. (5) An important insular range in Madagascar.

The Atlas mountain system is almost European. Its main axis is an irregular line, whose principal direction is WSW. and ENE. This line reaches from Cape Geer, on the Atlantic, to the coast a little north of Tunis. There is an imperfect division of this part of the chain into Greater and Lesser Atlas, but the whole is really a succession of crests, forming the division between the waters flowing into the Mediterranean, and those which flow towards and beneath the Sahara. The strike of the eastern or Mauritanian portion is E. and W., and the elevated Atlas of Marocco NE. and SW. There are among the mountains some of considerable elevation. The loftiest is estimated to attain to 11,400 feet. The general character of the chain is rather that of elevated table lands of small width (as in Central Asia) than that of a lofty serrated ridge, like the Alps. While, however, the sides of the mountains and their general summits often present this flattened character, the highest points are formed of great and inaccessible masses of detached rock rising perpendicularly.

An important offset of the Atlas stretches towards the north and terminates at Ceuta, showing a connection of the mountain chains and rocks of southern Spain with those of Africa.

On the western coast of Africa, south of the Sahara, and on the coast of Guinea, there are noble mountain masses rising 13,000 feet above the sea. These have not yet been traced satisfactorily to form a continuous chain. The Atlantic coast of Africa for 900 miles from Cape Negro to the Orange River is low, but within, at a short distance, there is a coast range which rises towards the equator, and is there extremely lofty. It is conjectured that this chain passes into or connects with a lofty east and west range.

The coast of south Africa from the Orange River to the Cape of Good Hope, thence eastwards to Natal, and northwards on the east coast to the Zambesi River, exhibits a series of ranges of high ground parallel to the coast, rising in places into lofty mountains. These are only interrupted where the Zambesi enters the sea. The island of Madagascar has a yet more magnificent mountain range rising to 12,000 feet, and being parallel to that of Lupata on the main land.

Recent discoveries in African geography have thrown much light on the physical geography of the country generally. Among other matters the existence of exceedingly lofty mountains, a few degrees south of the equator, and at a distance of some 300 miles from the Zanzibar coast, has been proved by the partial ascent of Kilima-njaro by the late Baron von Decken, and the sight of Kenia, about 200 miles further north, and on the very line of the equator. These mountains are not less than 20,000 feet in height, and the snow line on them is sometimes within 13,000 feet of the sea, though permanent only at 17,000 feet. They probably connect with the Abyssinian range, a mass of rugged mountains torn by ravines, but with intervening cultivated plains. They include a chain running for 300 miles parallel to the coast of the Red Sea, rising in places to 10,000 feet. At some distance within the country there is another and loftier plain (the mountains of Samen), giving rise to some of the principal feeders of the Nile. These are estimated at 15,000 feet, and extend southwards. The late Captain Speke received information while on his last journey to Victoria Nyanza which induced him to believe in the existence of an equatorial range west of that great lake.

We come next to the mountain systems of the new world. These are neither less extensive or less important than those already described, but they are more simple, and unlike those of Europe, Asia, and Africa. They form a single principal chain, close to the western side of the continent, instead of dividing it into two parts of almost equal area. Three main groups of mountains—the Rocky Mountains in the north, the Mexican Andes in Central America, and the mighty Cordillera of the Andes, commonly so-called, (reaching from north to south in an unbroken line through south America)—these together make up the chain. Its total length is nearly 10,000 miles. Though simple in its main features it is complex in its details, consisting of two or more chief axes. Towards the north these are rather widely separated, and only at a few points do the ridges culminate to peaks above 10,000 feet in height. In the central part there are very extensive lofty plateaux, not always bounded on both sides by mountains. The southern division, ranging from the Isthmus of Panama to Cape Horn, is narrow, but double throughout, and projects spurs to the east, dividing south America into river-basins, which, from the position of the mountains, and the form and dimensions of the land, east of the mountains, are among the largest in the world.

The Rocky Mountains run for 3,000 miles in two parallel chains from the Arctic Ocean to the plains of Mexico, and are flanked by two other parallel ranges to the west, namely, the Sea Alps of the north-west coast and the mountains of California. The latter range, for the chief part of its course, is separated from the others by the sea.

These two main chains, together with the southern extremity of the third (the Sea Alps of the north-west coast), commence at about the tropic of Cancer, and thence proceed northwards to about latitude 42° N., where they form a mountain knot of very considerable elevation (the Snowy Mountains), transverse to the main north and south direction.*

The general character of the two ridges which enclose the great plains of Mexico, and of the Sierra Madre, which rises between them, is that of rugged and irregular hills, whose summits are not more than from 500 to 2,000 feet above their bases. These are often separated from each other by abrupt declivities, and traversed by deep transverse valleys. Further north, and between latitude 29° and 34° N., there are two ridges somewhat more distinct, but not lofty. Still further in the same direction, and near the Snowy Mountains (latitude 42°), the mountains rise abruptly from the east, towering to a great height, and consisting of ridges, knobs, and peaks, many of which are covered with perpetual snow. These vary in altitude from 10,000 to 15,000 feet, and are all on the eastern side of the range. The descent of this lofty mountain chain to the west is not so rapid as in the east, and the parallel range on the other side of the Rio del Norte, whose valley separates the eastern from the central ridge, and which also rises sharply from the east, is less considerable in the number and elevation of the lofty peaks that surmount it. It is still, however, an important chain, and is separated by a very wide interval of sandy desert from the Sea Alps of California.

---

* It is usual to consider that the Rocky Mountains terminate at the great bend of the Rio del Norte, latitude 29°; but the Cordilleras that continue in the same direction to the south of that bend seem to prove, that although part of the table land of Mexico, the chain may, in all essential points, be regarded as the continuation of the mountain system and as forming a true connecting link with the Andes.

Most of the desert tracts in this part of North America are covered with salt, and are more or less volcanic.

Past the important transverse range of the Snowy Mountains and the Black Hills—which in the west attain near the coast an elevation of 10,000 feet, but die away in the east as they approach the upper valley of the Missouri—the Rocky Mountains or Oregons, as they are there called, exhibit two principal ranges running parallel to each other at a distance of 100 miles, and continue as lofty and rugged elevations to a very considerable distance, with a breadth of 30 to 40 miles. The mean height of the chain is here 9,000 feet, and the parallel western range is lower, but wider. The mountains rise again as they near the Pacific coast, and form a distinct and important chain. The principal ranges for some distance we have already described. They are lofty, but not uniform and continuous, rather forming extensive groups of mountains than true ridges, and being over-topped by high peaks, two of which, in latitude 52°—53° N., (Mount Hooker and Mount Brown) attain elevations of nearly 16,000 feet. Still further north the eastern range remains lofty, but it gradually diminishes in height till it sinks into an insignificant range towards the Arctic circle.

A part of the coast range near latitude 60° presents a number of very lofty peaks, one of which is Mount Elias, the highest mountain in North America. It is estimated at 17,800 feet, and the chain of which it is the culminating point, extends to the south-east for nearly 100 miles along the coast, and terminates with Mount Fareweather, whose height is 15,000 feet.

The Cordillera of the Andes is a continuation of the Rocky Mountains, connecting with that chain by the mountains of Central America. The Isthmus of Panama on the south, and that of Tehuantepec on the south, separate central from South and North America. This included district has a length of about 1,200 miles, and varies in breadth from 20 to 400 miles. It is a confused mass of three mountain groups divided by valleys running from the Gulf of Mexico to the Pacific. Many of the mountains are low, but most of the district consists of lofty table land, and far loftier mountains, of which several are active volcanoes. Guatemala is the northernmost of these table lands, and is intersected by deep valleys. It includes three volcanoes, all active, and terminates in parallel ridges of mountains running from east to west, rising from 7,000 to 10,000 feet above the plain. The Cordillera of Veragua, about 9,000 feet high, is the southernmost, and between Veragua and Guatemala is the Mosquito country and Honduras, containing lofty mountains. South of Panama we enter South America, and the great chain of the Andes, properly so-called.

The Andes are subdivided, both geographically and geologically. There are six principal sub-groups, which may be described under the following names:—(1.) Andes of New Granada; (2.) Andes of Quito. These two are sometimes called the northern Andes. (3.) Peruvian Andes; (4.) Bolivian Andes. These two form the central Andes of some authors. (5.) Chilian Andes; (6.) Patagonian chain. These are the southern Andes. From the first group proceed the feeders of the Orinoco, from the second and third those of the northern or Marañon branch of the Amazons, and from the fourth those of the southern branch of the same great river. The Parana is chiefly fed from the Brazilian Mountains, but partly from the Chilian Andes.

The Andes chain consists of a double or treble axis, with numerous very lofty plains, where these different ranges come together. Such plains are called *knots*, and they present phenomena of the most singular kind, which will be described when we consider the plateaux or lofty plains of the earth.

For the most part, the western or coast range of the Andes is the loftiest, and that of which the largest proportion rises above the snow line. It is generally ascended with difficulty by rugged paths to an elevation where the frozen plains, called *paramos*, are found, and from these rise colossal peaks, many of them volcanic, but covered with perpetual snow. The country (which would be very improperly described as valley) that extends between the two mountain axes, in those parts where the chains do not form a knot, is broken, uncultivable, and solitary. Its width varies, but is never very considerable in proportion to the magnitude of the chain, and it is necessarily very varied in aspect, climate and vegetation. The northern portions of the chain being tropical, and the southern parts in high southern latitudes, there are extreme differences in the various divisions, and each may be regarded as a special group, though there is really no strict demarcation from the Isthmus of Panama to the extremity of Patagonia.

The whole chain of the true Andes, grouped geographically, as we have just described, is divided physically by those singular "knots," or converging points of mountain ridges, that exist in other mountain chains, but are nowhere seen in so characteristic a form. Estimated in this way, however, the geographical division remains. To render the whole system clear it will be best to commence at the southern extremity, where the chain rises out of the ocean and show the successive divisions as they approach the equator, and finally pass away in New Granada.

The Andes of Patagonia rise suddenly out of the sea at Cape Horn (or Hoorn) to a height of 3,000 feet, by a chain of peaks ranging from 3,000 to 6,000 feet, but broken at intervals by deep gorges penetrated by the sea, and resembling the fjords of Norway. This chain connects with the main continental chain in latitude 52° S., there rising to about 6,000 feet, immediately from the Pacific. From the mode in which the coast is lined with islands, and broken by these fjords, it is manifest that the chain is continued beneath the sea with a true mountain character, the islands being the summits of the submerged mountains. The same general condition extends still further to the south, connecting the Andes with the unknown land of the Antarctic seas, and separating the Pacific from the Atlantic basin in a manner that will be further alluded to when we come to the description of those great oceans.

From the point where the Cordillera enters the main land the mountains continue to rise, and at length in latitude 43° S., they reach to the height of 8,000 feet, rising immediately from the sea, covered with perpetual snow, and giving rise to enormous glaciers. The Patagonian Andes exhibit no elevation more considerable than about 8,030 feet.

The Andes of Chili do not approach so near the coast as those of Patagonia, but they attain a much greater height, presenting, also, hilly districts, flanking the main chain. This Cordillera (as mountain chains are called in the Spanish language) has 12,000 feet of mean elevation, but one mountain, Aconagua, rises to 23,000 feet. The mountain tops are rarely above the level of perpetual snow, which, in latitude 33° S., rises to 12,780 feet. The precipices on each side of this part of the range are frightful, and several volcanoes erect their conical peaks above the flat summits. The Chilian Andes terminate at the knot of Porco and Potosi. This knot is above the snow line, (at this place 17,000 feet above the sea).

From about the 20th degree of south latitude, the chain takes the name of Peruvian Andes, and is separated from the Pacific by a plain about 60 miles broad, extending for 1,250 miles to the north. No rain falls on this district. The same plain extends as far as the Isthmus of Panama, but, in its northern continuation, is damp and clothed with luxurious forests.

The Peruvian Andes proceed for about 250 miles, in a somewhat north-westerly direction, to the knot of Cuzco, in two principal ranges of great elevation, between which is the table land of Desaguadero. The whole breadth of country, including the two ranges and the plain between them, is only 300 miles, but a multitude of snowy peaks rise on each side, varying from 18,000 to 22,000 feet in absolute height above the sea. The elevation attains a height exceeding 25,000 feet in the middle of the eastern range. A very important eastern spur of the Andes (the Sierra Nevada de Cochabamba) is given off from this range of the Bolivian Andes.

The group or knot of Cuzco is a remarkable range of high ground, having an extent of surface three times as large as Switzerland, with a mean height of 8,300 feet. North of it extends the plain of Bombon, at an absolute elevation of 14,000 feet. This is only 18 miles broad. On each side rise ridges, which unite again in the knot of Pasco and Huanuco. between the 11th and 10th parallel of south latitude, 11,800 feet above the sea, whence proceeds a triple range of somewhat lower elevation, (rarely amounting to 10,000 feet), terminating at the knot of Loxas.

From this point, at which the elevation varies from 6,400 to 8,300 feet, the summit of the Andes forms a narrow table land for 350 miles, hemmed in by some of the loftiest mountains of the new world. Among these, Chimborazo (21,420 feet), Cotopaxi (18,858 feet), Antirana (19,126 feet), Cayambe (19,625 feet), and many others, form a series of mountain cones, many of them volcanic, which surround the remarkable table land on which Quito is situated, and attest the activity, energy, and vast force of the subterranean powers, which are often still recognised in the earthquakes and eruptions so characteristic of this remarkable district. One of these peaks (Cayambe) is traversed by the equator, and all of them are situated under the immediate influence of a tropical sun, affording in the ascent of their lofty slopes every variety of climatal peculiarity that the surface of our earth will admit.

North of the equator is the knot of Los Pastos, (10,300 feet), beyond which the chain of the Andes begins to diverge, one branch going off to the north-east into Venezuela, bounding the Llanos of the Orinoco and spreading out into the table land of Sta Fé de Bogotá, with an altitude of 9,000 feet. Another (the central branch) runs due north, at a mean height of 10,000 feet, but attains a height of 18,314 feet in the Peak of Tolima. The third or western branch is much lower, and only 20 miles broad. They form, together, an almost impassable barrier, and proceed through the knot of Antioquia, (7,000 feet), to the Isthmus of Panama.

A small east and west coast chain extends in Venezuela north and east of the eastern continuation of the Andes, the hills rising to the height of about 7,000 feet, directly from the sea. The western extremity of this range is the lofty mountain of St. Martha, which, at a height of 19,000 feet, and deeply covered with perpetual snow, rises as a landmark in the extensive plain between the delta of the Magdalena and the Lake of Maracaybo.

On the Atlantic coast of South America the only considerable mountain chains are in Brazil. Two parallel ranges cross the country from north to south, the greatest height attained being between 6,000 and 7,000 feet. In North America the Alleghany Mountains commence in Alabama, and range with a breadth of from 60 to 120 miles to the Catskill Mountains, on the Hudson. Their greatest height (in North Carolina) is 6,476 feet, but their general range is less than half that elevation. The Catskills rise to nearly 4,000 feet.

In the continent of Australia there are no lofty mountain chains. One important system, however, ranges along the east coast, in a nearly north and south direction, through 35 degrees of latitude, and is then continued into New Guinea, connecting itself with the islands that join Asia. It is also continued southward into Tasmania. This chain nowhere recedes more than 150 miles from the coast. Its height varies in different parts from 2,500 to more than 5,000 feet above the sea; the loftiest point, Mount Kosciusko, being 6,500 feet. These mountains are exceedingly wild and rugged, and have numerous spurs projecting at right angles from the chain, forming dark and almost subterranean gullies nearly inaccessible, and helping to render the chain much more formidable than far loftier elevations in other countries. The extension of this chain into New Guinea is very much more lofty.

New Zealand exhibits a mountain chain of great elevation, ranging nearly parallel to that of Eastern Australia. These southern alps include a large number of pyramidal peaks, rising more than 10,000 feet above the sea. Mount Cook, the highest of all, is 12,460 feet high. This great back-bone runs through the islands from north-east to south-west, about 30 miles from the west coast. Very lofty passes, from 6,500 to 8,000 feet high, intervene between the peaks. Gigantic glaciers occupy the higher valleys, and reach down more than 12 miles into the lower country. Many of the mountains are volcanic.

Such is a brief outline of the great mountain chains of our globe. Grand as they are they are not excessive compared with the earth's diameter, and there is nothing in their history that removes them from the existing state of things. To a very large extent they are water-worn having been denuded of coverings of softer and newer rock. All that has once covered them has been carried away during the long process of elevation and now forms other and yet more recent deposits. These are either still at the sea bottom or have been lifted up since the commencement and during the progress of the upheaval that has converted a former smooth sea bottom into a lofty and serrated ridge.

CHAPTER VI.

HILLS AND VALLEYS—PLATEAUX AND LOW PLAINS.

1.—Hills.

Hills and mountains are often regarded as involving similar conditions of the earth's surface, differing only in degree; and it is difficult to give distinctive definitions in popular language that shall be both clear and unexceptionable. But in physical geography we may, with some advantage, distinguish between them. We may regard as mountains either isolated masses of rock of great elevation, or several ridges connected together by similar rocks in a definite manner, and forming continuous chains. In a small district, however, very moderate elevations will be regarded as mountains; while in a country of great extent, very high ground will still be regarded as hill-country. Mountains are generally in continuous groups, and hills, on the other hand, are disconnected and isolated. Geologically, mountain chains exhibit in some part of their structure metamorphic rocks, from whence we conclude that the whole mass now elevated was once buried at a very great depth below the earth's surface. Hills, on the other hand, though they may be formed of metamorphic rock, more usually consist of the ordinary stratified rocks of the district. Both have been very greatly modified by weathering and denudation, or in other words, have been worn away by the action of water and weather since they were formed; but mountains have generally been cleared of a large part of the soft material once covering them, and are left projecting, at least in part, above this covering, while the hills are rarely laid bare so completely—soft rocks still covering their surfaces. Mountain chains are generally lofty, and hills only of moderate elevation. Moun tain forms are jagged and picturesque—hills present smooth and rounded outline. These are general distinctions, visible to the eye. In structure, there are some others, but they are of little importance, as the distinction has never been made with much accuracy, and we need not now attempt it. There are many exceptions to any nomenclature. Thus, the Malvern Hills, according to strict definition, are mountains.

The subordinate elevations of a continent may be of great absolute height, although very little above the level of the surrounding plains. It is evident that elevation is relative, and that hills may be several thousand feet above the sea and yet only a few hundred feet above the general level of the land from which they rise. Thus, the mountains of Wales, and the hills in the great valley of Switzerland, attain nearly the same height above the sea; but inasmuch as the first rise directly from the sea without intermediate terraces of land, and the others rise from a lofty plateaux, the mountain character in Wales is as well preserved as that of the Alps themselves, while the numerous hills of Switzerland are simple undulations. Hills, therefore, are distinct physical phenomena, and are of some value as marking the general character of a district. They are also important as frequently marking the limits of natural drainage areas. They assist in the natural drainage, partly by attracting clouds and condensing them into rain; partly by affording slopes, down which the rain passes into wider channels between them; and partly by giving a certain amount of shelter against the influence of prevalent winds. Such winds, passing over plains of great extent, become intensified, and acquire a very mischievous strength. In hilly countries they are broken up, distributed as it were among the valleys, and greatly checked in their course.

Hilly ground sometimes occupies an intermediate position between mountain tracts and perfectly flat plains. There are, however, very extensive districts far away from mountains that are gently undulated or rolling. The cause of the former condition may be found in the geological structure of the district, and they are produced by such disturbances and subsequent denudations as those to which the mountains themselves are due. The latter are probably the result of denudation only, if we include ice with water as a cause of denudation. In some cases the hills are of the same rock and of the same hardness as the intervening lower spaces or plains. In others, they are of harder rock, and mark important facts in the geology of the country. There are, however, many hills of sand, clay, or gravel, consisting of heaps of such material super-imposed on hard rock, with which they are quite unconformable. There are many well-marked hilly districts. In England, as those most likely to be most familiar to my readers, we may mention the Malvern Hills, of syenite, which are really mountains; the Cotteswold Hills, of oolite, resulting from elevation and denudation; and the range of the South Down Hills, of chalk, whose form is due to weathering and denudation. All these are low but perfectly distinct, and all are geologically marked. The two latter represent the escarpments of important strata, very uniformly distributed through the country. The former, though they have no doubt undergone enormous denudation, present now an excellent example of the class of elevations of hard rock which, on a larger scale, would be called mountain chains. In Europe, north of the mountain chain, where there is a vast expanse of plains, these are broken at intervals by a few hill ranges. Among them are the Waldai Hills, not more than 300 feet above the sea, but very well marked. But we need not pursue the subject further, as groups of hills, though locally interesting, and often very picturesque, are hardly of sufficient importance in physical geography, or sufficiently distinct as physical phenomena, to make it desirable to designate them as belonging to the various natural divisions of the globe. They are often, however, suggestive to the geologist, and can never be neglected with safety, in an estimate of the physical features of a country, especially in reference to climatal questions.

It is not always possible to adapt the common and recognised language of every-day life to any strict rule of special terms; and it has already been pointed out that few words are less manageable in this respect than those we are now considering. What is a hill in one country is a mountain in another; and neither by form, structure, height, or any other peculiarity, can we draw a line that shall include all that it is desirable to include, and exclude what has no clear right to be included.

But hills, though they often cannot be distinguished with certainty from mountains, can hardly be mistaken for plains; nor are plain countries likely to be described as hilly. Even this, however, is not a rule without exceptions, as some of the great plateaux, and others smaller but sufficiently definite, are occasionally so far intersected by gorges and ravines, and the sharp edges of the fractures are so far worn away, that their table-shape is almost lost sight of, and they become reduced to an appearance of hills and valleys, more or less systematic. Those who have visited the Saxon Switzerland on the right bank of the Elbe, not far from Dresden, may call to mind a tract of land certainly originally a plateaux, but now reduced by the eroding action of water to a number of detached and grotesque protuberances, which a little rounding might convert into hills.

The Quantock hills, in Somersetshire, and the hills of Derbyshire, afford other examples; and in different parts of Europe are innumerable illustrations of similar kind. The Saxon Switzerland is in a sandy district, and its hills are intervals between valleys of erosion. Another equally picturesque tract of limestone in the north of Bavaria (known as the Franconian Switzerland) exhibit numerous phenomena of the same nature produced in the same manner, on a very different material, may be studied with advantage. Thus hills, at least in some cases, are derived from high plains or plateaux, by the continued action of the weather on certain rocks.

2.—VALLEYS.

Valleys are by no means to be regarded as necessarily in contradistinction to hills, although it is convenient to consider them at this point of our history of the land. Geographically, they represent depressions occupied partly by streams that run through them; but they are often of extreme width, compared with the rivers from which they receive their names. In mountain districts they are enclosed by lofty walls; but across great continents, away from the mountains, they are bounded only by hypothetical and assumed limits. There are thus narrow and shut-in valleys, generally at a high level above the sea; and open valleys, scarcely different, except in name, from low plains.

The upper valleys in mountain districts are often remarkable for magnificent scenery. Receiving the snow from the mountains, they afford the shelter in which glaciers accumulate. They are occasionally blocked up by some natural obstacle, and form the beds of lakes. They fall rapidly, and, the rivers rushing down them, leap from rock to rock in cascades and waterfalls. Their sides grooved and scratched by ice, or smoothed and worn by the constant erosive action of water, exhibit more clearly and completely than any other parts of the earth's surface the nature of the forces that have acted to produce its existing physical features. They are thus landmarks, and indications of progress as well as of destruction.

Geologically, there are valleys of fracture, or fault, and valleys of erosion. All rocks, in being lifted to form mountain masses, must be cracked and broken, and, in many cases, one side is lifted higher than the other. Thus are formed mountain gorges, some of which are of the grandest character. Very soon, these crevices, or fissures, are acted on by running water,—their walls are undermined and broken down—the rain forming a stream or increasing a stream already in existence, rushes down them, pounding and carrying away a large proportion of the fractured walls, and leaving some part as a rocky bottom. In this way are produced those varieties of form which astonish and delight the traveller, and speak with such distinct voice to the student of nature, teaching him the true origin of appearances which he might at first regard as proofs of convulsive action, or of disruptions inconceivably greater than could be caused by any force now recognised.

All valleys are more or less distinctly valleys of erosion. Many are nothing more than this, and are the result of the daily and ceaseless grinding power of running water, increased greatly in effect by atmospheric change. In some countries, the very beginning of the formation of a valley in a plain may be seen, and its rate calculated, but, more usually, the work is noticed only when it has already been so long in course of proceeding, that the actual spot, where the valley originally commenced, cannot be detected.

The lower valleys, or continuations of the upper and more technical and typical valleys, are illustrated, in England, by the valleys of the Thames and Severn, as they open out to the sea. The valley of the Rhine, sometimes open and wide, sometimes shut in by approaching mountains, is a better example. The valley of the Danube is on a still nobler scale, especially where it spreads out in the plains of Wallachia, after being shut in at the Iron Gate, where the Carpathians are crossed. But it is chiefly in the countries where the largest rivers exist, that the phenomena of great valleys must be studied. The valleys of the Ganges, in India, of the

Mississippi, in North America, and of the Amazons, in South America, are of this kind. They are vast spaces of comparatively low and level ground, and thus pass into, and are lost in the gigantic low plains which are regarded as a somewhat different condition of the surface. There are other vast spaces hollowed out also by water, but with no natural outlet to the sea; and these, too, must be regarded as valleys, though of a somewhat different kind. The valleys of the great rivers of Southern Africa are of this kind, and, perhaps, some of these of Australia.

Valleys have been described as the great natural highways of the world, and in a very important sense they are so. When traversed by navigable rivers, they facilitate progress, and the earliest civilization of the world has probably been governed and guided by these physical conditions. Greece and Rome, however, owe nothing to great valleys; although India, China, and Egypt may be quoted as examples in favour of this view. In modern times, human interests are so closely connected with easy communication, that valleys would seem to have once more taken their place among the necessities of success in new colonies, were it not that Australia is of all countries that which has the fewest of these advantages.

III.—High Plains or Plateaux.

Under the name *Plateaux*, may be included all those plains whose mean elevation exceeds 600 feet, and which, for the most part, rise at once, or rapidly, from the sea, or from lower plains. This definition is arbitrary, but convenient. Of such plains there are many in all the principal divisions of the land. Some of them are very greatly elevated, and some of enormous extent. They are everywhere marked by peculiarities of climate and vegetation. They often occupy positions between and amongst mountain ranges, but to this there are important exceptions; some apparent, some real. They always connect themselves with the geological history of the district in which they occur, and often with the great axes of elevation that have produced the most striking physical features. We must consider them systematically, and shall then proceed to describe the low plains.

To begin with our own country—which, from its small area can only present phenomena on a minute scale, but which, being necessarily familiar to its inhabitants, is very convenient for reference—we find in it a plateau of chalk and another of the oolites. The granite of Cornwall affords a third. The Wiltshire Downs, extending northwards and eastwards, illustrates the first, and connects true hill structure with that of a plateau, acted on by weathering and denudation. The general range of the Cotteswold hills, extending through several counties, and having a general direction from south-west to north-east, but everywhere of limestone, is a still better example. Dartmoor, and the adjacent granite district, is another equally well marked. None of them, indeed, are very extensive, but all have certain characteristic features, both of vegetation and climate. There is a general feeling that the air is more fresh and invigorating, and the country more open on these higher grounds, than in the low plains and valleys.

France, also, has its plateaux. In the north, they are not much more elevated, nor greatly more continuous than those of England, and they are there of irregular elevation, but in the middle of France we find true plateaux of limestone rock, and others of basalt. Both are of moderate extent. In the extreme east of Europe, and also in the Iberian peninsula, similar phenomena are represented in a distinct form, and on a grand scale. The latter are more characteristic; the former much more extensive. Thus, to the north of the great German and Sarmatian * plains there is a plateau of moderate elevation, extending for about 1,500 miles in length. The width is sometimes less than 50 miles; in others, as much as 200 miles. The whole is of a very moderate elevation. This plateau separates the low plains of central from those of northern Russia. Between the Sarmatian plain and the Steppes of little Russia, is another—the Carpathian plateau, extending for nearly 800 miles to the east, though not without important interruptions, where it is crossed by the Dneiper, the Don, and the Volga. This, also, is low, though abruptly raised from the sea. It is only in the Iberian peninsula that we find in Europe a large elevated plateau.

The central plateau of Spain is a tract consisting of nearly 100,000 square miles of country, whose general elevation is

---

* Sarmatia was the name given by the Romans to the country in Europe and Asia between the Vistula and the Caspian. It is partly Asiatic.

from 2,000 to 3,000 feet above the sea. It is partly surrounded by mountains, and several granite ridges (*sierras*) rise out of it. Some of these Sierras (as the Sierra Nevada) attain a very great elevation; others, the Sierra Morena and the Guadarama are less lofty. The great plateau is intersected by ravines, through which the rivers flow. The surface consists, for the most part, of limestone rock, covered with a thin soil. The limestone is somewhat marly, and large crops are grown on it, the whole country being favourable for corn crops, and the vine thriving in certain localities. The climate on this table land is somewhat extreme, being hot and parched in summer, and cold in winter. In the low lands on the south and west coasts, the climate is sub-tropical, and the contrast is very striking.

The plateau of Spain extends into Portugal. It is separated from France by the Pyrenees, which rise as a wall between the high land through which the Ebro runs, and the low plains of Languedoc. Beyond Languedoc, are the small limestone plateaux of central France, which thus have a certain correspondence with those of Spain.

Asia is the country of plateaux. Lofty plains extend, occasionally broken by mountain ranges, from the shores of Asia Minor to the Pacific Ocean. The breadth of the plateau, at first rather narrow, expands, by degrees, till it amounts to as much as 2,000 miles. The altitude is always considerable. In many places, the plains are rent by enormous fissures of great depth, traceable to considerable distances.

The western portion of these great plains consists of the table lands of Arabia and Iran, or Persia. Each occupies an area of nearly 2,000,000 of square miles, varying in height above the sea, from 4,000 to 7,000 feet. The eastern portion is very much larger, amounting to nearly 8,000,000 of square miles. It is, also, much loftier; some parts attaining an elevation of 17,000 feet, which is higher than the loftiest mountain peaks of Europe. These high lands rarely present a continuous and absolute level, or resemble, in this respect, the low plains, under whatever name they are described. They are bounded by mountains, and some of the loftiest mountains of the world rise out of them. They not unfrequently, also, exhibit mountain features.

Among the great plateaux of western Asia are included the cold, tree-less plains of Armenia, 7,000 feet above the sea, and the great salt desert and adjacent sandy deserts of Irak and Kerman, in Persia. These are almost without cultivation; the sands being driven about by the wind, or the soil covered with an efflorescence of saltpetre.

Separated from these by a spur of the Himalayan Mountains, and from the plains of Hindostan by the great Himalayan chain itself, are the table lands of Thibet in the south, and the vast plateau of the deserts of Gobi and Scha-mo in the north, the latter extending to the foot of the mountains of eastern China that border the Pacific. All this part is of extreme altitude. It is traversed by no less than three mountain ranges. Throughout the whole district there are no low plains, for the level of the water of the great lake of Baikal, one of the largest sheets of water in Asia, is 1,800 feet above the sea.

The deserts of Gobi, Scha-mo (sand desert), Scha-ho (sand river), and Hanhai, run in a NNE. direction with little interruption from eastern Thibet, near the Hindoo Koosh mountains, for a distance of nearly 3,000 miles. The breadth of the table lands varies from 500 to nearly 1,000 miles. The mean elevation of the eastern part, where it has been best explored, between the sources of the Seleuga and the great wall of China, does not exceed 4,000 feet, but in the western division is much greater. The mountains there rise to about 13,340 feet above the sea, and the mean level of the plains is estimated at 11,510 feet.*

Thibet is divided from east to west into three portions. Upper and Middle Thibet are nearly 10,000 feet above the sea, but Little Thibet is only 6,300 feet in some parts, although the plateau of Deotsuh, measured by Vigne, was found to be 11,977 feet. The region thus designated is not an unbroken plain, and there are few real plains within its area. It is an irregular plateau with mountains rising from it; some of these are exceedingly high. Round Ladak the level is 13,430 feet, and the plateau of the Sacred Lakes of Manasa and Ravanabrada is upwards of 15,000 feet above the level of the sea.

South of the Himalayan chain and the valleys of the Ganges and Indus are the high lands of the peninsula of India. These consist of the plateaux of Malva and the Deccan, separated by the Vindhya range of mountains. They are extensive and well marked. Much of the surface consists of sheets of lava poured out under water, and to this is owing the generally flat and tabular form of the country, and the wide gorges produced by the action of water on the cracks in the wide lava sheet. The plateau of the Deccan is terminated towards the sea by the eastern and western Ghâts. The plateau is considerably lower than the mountain chains.

---

* Humboldt. "Aspects of Nature," vol. i. p. 79.

Table lands occur occasionally in islands. Thus the Faro islands situated due west from Norway rise at once 2,000 feet, and present nearly the same elevation in every part of the group. Even the north-west extremity of Scotland, and the central part of Ireland, exhibit the same peculiarity, but the elevation is much smaller.

Africa consists of a ring or belt of table lands often of considerable elevation, rising rapidly from the coast, or from a strip of low lands near the coast, and then retaining the same elevation for very great distances. Within these high lands are the vast lakes recently discovered, and it would seem that the chain of plateau is almost unbroken round the whole coast. The rivers that escape from the interior are thus obliged to traverse enormous distances to reach the sea. The height of the plateau is generally from 3,000 to 6,000 feet. At the Cape of Good Hope in the south the breadth of the plateau is nearly 700 miles, and the Cape of Good Hope itself is the extremity of table land of a pyramidal form jutting out into the sea. The mountains of Abyssinia on the north-east rise out of the plateau, and so do the extremely lofty volcanic cones recently discovered. There appears to be but one break in the high land, between the Cape and the north-eastern extremity of the continent of Africa. Through this the Zambesi makes its way, after a long course in the interior. The streams on the western side south of the equator appear to drain chiefly the plateau itself, not crossing it by any natural fissure.

Australia is a country in which low plains and plateaux prevail almost to the exclusion of mountains and valleys. It is only on the eastern side that there is any considerable mountain range, and along the whole of the south and west coasts the land rises immediately to the vast flats of the interior. Thus almost the whole country partakes of the same geographical features, and this monotony is unfavourable for the development of the higher vegetable and animal organisms. The greater part of the western and southern side of Australia seems to consist of plateaux of moderate elevation.

In north America there are plateaux towards the north, and also between the coast range and the Rocky Mountains on the west coast. The Arctic highlands, consisting chiefly of barren grounds beyond the 60th parallel, and a somewhat extensive tract crossed by the upper waters of the streams that enter the northern lakes (Athabasca, Winnipeg, &c.) are elevated plains, but hardly attain the character of plateaux, as they rise, for the most part, very gradually from the low plains, through which run the Mississippi and its tributaries. By far the most important of the North American plains is the 'Great Basin' of California and Oregon, reaching from Mexico northwards into the Russian territory. Its width is inconsiderable, compared with the great length of this plateau, which cannot be estimated at less than 2,000 miles, while the distance from the Sierra Nevada to the Rocky Mountains nowhere exceeds 600 miles, and is generally very much less. The greater portion of it is little known. It is at least 128,000 square miles in extent, and almost entirely without human inhabitants. It is volcanic, and full of salt lakes, the largest of which is 4,200 feet above the level of the sea, and is connected with the lake of Utah. The mean elevation of the plain is estimated at 6,000 feet above the sea. This Californian plain or Great Basin contains some extensive deserts, but is on the whole cultivable. It is crossed by a mountain chain, and also by the Colorado River, which runs through gorges of the most picturesque magnificence. The descent to these and the other gorges and ravines which abound, especially in the southern part of these plateaux, is generally extremely precipitous. The plains rise in successive steps, and this terrace character is very distinctly retained over a wide tract.

Central America is remarkable for the lofty and rich plains of Mexico, out of which rise many very lofty volcanic mountains. The whole country lies between the equator and the Tropic of Cancer. It consists of an irregular mixture of table land and mountain, very steep on the western side, and with low lands between the eastern extremity and the Gulf of Mexico or Caribbean Sea. An important part of the whole —the table land of Guatemala—consists of undulating verdant plains, about 5,000 feet above the sea, spreading east in the peninsula of Yucatan, and everywhere intersected by deep valleys. The land is partly covered by magnificent forests, as its name in the Mexican language is understood to imply. The plains beyond and around Mexico are as much as 9,000 feet high, but diminish towards the north. They extend in a long and narrow strip to the upper waters of the Rio del Norte.

In South America there are numerous lofty plateaux, but they are more remarkable for height than extent. They are situated in and among the converging lines of the various divisions of the Andes. One of them, the Desaguardero, has an absolute altitude of 13,000 feet above the sea. It extends for about 500 miles along the top of the Andes, and has a breadth varying from 30 to 60 miles. The whole area is about 150,000 square miles. It presents a considerable variety of surface. The city of Potosi stands upon it at an altitude of 13,350 feet, and the lake of Titicaca, whose level is 12,871 feet above the sea, is on its lowest point. The table land of Quito is smaller, but also remarkable. It is 200 miles long and 30 miles wide, and is nearly 10,000 feet above the sea. It is bounded by a range of the most magnificent volcanic mountains in the world. Besides numerous small, but lofty plains, amongst the mountain chain of the Andes, there is a large tract of high land on the eastern side of the chain in Patagonia. The Patagonian steppes are only of moderate elevation. They are at a dead level, and covered with shingles to a considerable thickness. These stones have all been brought down from the Andes, and are water-worn. Over them are innumerable boulders, or stones of larger size, which have probably been transported by ice. The vegetation of these plains is stunted, and they support but a small variety of animals, though the tribes most abundant are curious and anomalous. They are, however, extremely interesting in connection with the extensive low plains of the eastern part of South America, which are more remarkable and more extensive than any others on the face of the globe. Ranging from latitude 45° S. to 12° N. latitude without interruption, they exhibit a not very ancient sea-floor for a distance of nearly 4,000 miles under circumstances more than usually favourable for examination.

The following tabular statement of some of the principal high lands in different parts of the world is partly taken from Humboldt in his "Aspects of Nature," and though by no means to be depended upon as an exact statement, is valuable for reference:—

Plateau of	Auvergne (France)	1,087	feet.
„	Bavaria (Germany)	1,663	„
„	Castille (Spain)	2,239	„
„	Mysore (India)	2,942	„
„	L. Victoria Nyanza (Cent. Africa)	3,308	„
„	Popayan (New Granada)	5,756	„
„	Orange River (South Africa)	6,395	„
„	Axum (Abyssinia)	7,034	„
„	Mexico (Central America)	7,483	„
„	Quito (Andes)	9,528	„
„	Province de los Pastos (do.)	10,231	„
„	Eastern Thibet	12,000	„
„	Desaguardero (Andes)	13,000	„
„	Ravanabrada (E. Asia)	15,000	„

4.—Low Plains.

We come next to the consideration of the low plains. By this term it is meant to include such comparatively level surfaces as are little above the level of the sea. A very large proportion of the land is in this state; and it is, perhaps, best distinguished from the plateaux,—already described,—by its gradual rise from the sea to a low elevation; whereas the plateaux are loftier plains and rise more precipitously. Of low lands there are very extensive tracts, absolutely typical, and about which there can be no doubt. There are also large districts of an intermediate character, commencing near the sea and insensibly rising to a higher level. These are slopes. Parts of them may sometimes be regarded as plains, and other parts as plateaux. Though these doubtful and intermediate cases exist, they do not interfere with the possibility of drawing a line between two conditions of the earth's surface, exceedingly different. This is the more important, since the difference greatly affects climate, and the distribution of plants and animals.

True it is, that only in large tracts of land do plains and plateaux attain dimensions sufficiently extensive to influence climate; but after all, such plains exist in all the great continents; and all extensive tracts of land consist, for the most part, of such tracts. Let us consider some of the most remarkable.

In the great continent of the old world, where the Alps and Himalayans, extending westwards to the Atlantic and eastwards to the Pacific, connected by important intermediate chains, divide the whole into two distinct parts, the northern lands exhibit plains and plateaux in all their grandeur. Among them, in Europe, are the low flat lands of northern Germany, known as the Germanic plains; the Baltic plain, and the Tundra of Scandinavia and northern Russia; the Sarmatian plain of central Russia; and the steppes of Astrakhan and Little Russia. The Kirghis steppes and the Siberian plain, including the plains drained by the great rivers of northern Asia, form another group of nearly connected areas belonging to the class of low plains in Asia They are occasionally broken and divided by low hills, as the Waldai hills in Russia, and even by low mountain chains, of which the Ural chain is the most remarkable; but these rise to so small an elevation as to vanish in comparison with the vast range of low flat lands. Low plains are the distinguishing feature of the northernmost lands of the old world. They occupy a total area of not less than 4½ millions of square miles, of which the central portion, near the Caspian Sea, amounting to not less than 160,000 square miles, is a depression below the level of the ocean; while another portion, near the western extremity, would be overflowed but for the banks and dykes erected by man.

In the south-east of Europe the low plains that assume the name of *steppes*, are highly characteristic. They are elevated about 60 feet above the level of the Black Sea. Through them several very large rivers run, and they reach back towards the Arctic Ocean with little interruption, rising scarcely at all, but slightly interrupted by very low hills. These steppes are phenomena sufficiently remarkable to deserve a few words of description; and they cannot be visited, even in the most cursory manner, without exciting feelings of astonishment on the part of those hitherto only familiar with the broken surface of the greater part of civilized and cultivated Europe.

In these steppes the seasons are very strongly marked. In the spring and early summer the land is carpeted by flowers. In the summer it becomes parched, after yielding as food or hay a fair supply of mixed grasses, which may be stored for winter use; but in the latter part of summer and autumn it is perfectly bare and burnt up. In winter, which begins in October, the whole area becomes covered with snow, and this remains until spring. There are no trees on those great plains, and no enclosures of any kind; but at intervals the surface is broken by hollows scooped out of the plain, to a depth varying generally from 50 to 100 feet; and in most of these are villages, and some cultivation, especially on the borders of the plain and in the vicinity of the coast, or of the great rivers. There are, however, no roads, and indeed there is no material for making them. One may travel for hundreds of miles over the level surface of the ground,—over the turf in spring, through the thick dust in summer, and over the snow in winter,—without seeing a single object rising above the general surface of the plain. The post houses, at equal and distant intervals, are the only signs of humanity and civilization; and the cry of the bustard is one of the few sounds that break the terrible monotony and stillness. The dead level of thin pasture, even if luxuriant, soon fatigues the eye; and when the horses and cattle are away there is absolutely nothing for the eye to rest upon. The travelling across the steppes, conducted with great rapidity, in a kind of light cart, is thus not so difficult as it is tiresome. But it is only safe in summer; and when the snows cover the ground, not only does it become dangerous, from the wolves who take refuge in the hollows, but almost impossible, owing to the absence of landmarks. It is understood that an entire *corps d'armée* was lost in the steppes between the Dneiper and the Don, while attempting to reinforce the Russian army in the Crimea, during the war with England and France. Throughout the southern part of the steppes and in much of the country to the east, there is either a thin soil or no soil at all. This condition, however, gives place in the interior to a remarkable and extremely important black soil, of extraordinary richness capable of yielding inexhaustible supplies of wheat without any artificial treatment or any agriculture, except of the rudest kind. These parts of the steppes now supply enormous quantities of corn to the great markets of the world; and when opened, as they soon will be much more completely, by railroads and steam navigation on the great rivers, it is certain that both Russia and the rest of Europe will be great gainers. A wide range of the plains is, however, hopelessly barren, and all of them depend much on the occasional rains. When these fail the heat is excessive, and the sun rises and sets like a globe of fire, while during the day a thick mist covers the earth. The drought soon becomes excessive,—the small supplies of water, found at other seasons in the hollows, fail altogether; the air is filled with dust and impalpable powder; and the cattle and horses perish by thousands. In the winter the case is equally bad: fearful storms often sweep over the desolate plains; the dry snow is driven by the gales with a violence which neither man nor animal can resist; but the sky remains bright, and the sun shines cold and clear in the blue vault of heaven. These storms are especially frequent in the vast Aralo Caspian plain, which is depressed below the general level of the sea, and which is, to a great extent, an ocean of shifting sand.

The Siberian portion of the low plains of the great continent occupies more than seven millions of square miles, and is partly covered by rich black soil, on which grass and trees grow with luxuriance. Other and larger portions are altogether barren, and the whole tract is rarely visited. It includes plains, varying from a few feet to as much as 1,200 feet above the sea; but these are all perfectly distinct from the plateaux or high plains, whose level is from 6,000 to 10,000 feet.

Almost the whole of northern Asia, to the north-west of the volcanic chain of Thian-schan; all the steppes north of the Altai mountains, and a wide range of country reaching from the Upper Oxus to the Caspian, and from Tanghir through the Kirghis steppe to the Sea of Aral, belong to this vast system of plains. The whole of the Irtysch, and almost all the Obi, runs through them; while the Yenesei and the Lena, hardly inferior in magnitude, are also included in the same great system of low lands. The plains of Hindustan, between the flanks of the Himalayans and the table land of Malva, are also of the same nature.

Within the great area of elevated land, of which the mountain systems of the old world are the culminating lines and points, there are some tracts of low plains which belong, however, more to valleys than to plains. To the south of the chain are some others of greater importance. The largest of these is the plateau of the Sahara, or great desert of Africa, reaching from the Nile valley to the shores of the Atlantic along a distance of 2,500 miles, with a breadth which at one point amounts to 1,200 miles. It is estimated that two millions of square miles of land are contained within the area occupied by this plateau; and several portions of it, some of considerable extent, are barely above the level of the Mediterranean. The greater part of the plateau is unsupplied with water, but the low plains, called *oases*, are generally provided with springs, which often rise to the surface, and which are supplemented by water obtained by artificial borings. Most of these are on the eastern or Lybian side of the desert, and the largest is a hundred miles long and from one to fifteen miles in width. The others are much smaller. Those of the western desert are smaller, and much of this surface is covered with salt, owing to the evaporation of the water of brine springs that rise through the lands. The larger tracts of real desert are without plant or animal—not even an insect is heard, and no tree or shrub is seen during many days' travel. In the glare of noon the air quivers with the heat reflected from the red sands; but the nights and early mornings are chilly, owing to the radiation into the cloudless sky. The traveller is frequently deceived by extraordinary refraction, or *mirage*, produced by the irregular heating of certain strata of the air above these vast plains. Water is apparently seen in large pools; and the traveller and his camel are induced to hurry on in search of supplies which do not exist within hundreds of miles.

The desert of Arabia, though smaller than the Sahara, is hardly less remarkable. Unlike the Sahara, it occupies an intermediate position between plateaux and low plains. It has been described by Mr. Palgrave, a recent traveller, who has succeeded, not without great difficulty, in penetrating this little-known country. He speaks of it as "an immense ocean of loose reddish sand, unlimited to the eye, and heaped up in enormous ridges, running parallel to each other from north to south, undulation after undulation, each swell about 200 or 300 feet in average, with stout sides and rounded crests, furrowed in every direction by the capricious gales of the desert. In the depth between, the traveller finds himself, as it were, imprisoned in a suffocating sandpit, hemmed in by burning walls on every side; while at other times, while labouring up the slope, he overlooks what seems a vast sea of fire, swelling under a heavy monsoon wind, and ruffled by a hot blast into little red-hot waves. Neither shelter nor rest for eye or limb amid the torrents of light and heat poured from above on an unanswerable glare reflected below."

Through this desert the way leads to the central plateau of Arabia. This plateau is formed by two mountain ranges and the plateaux falling off from them. The northernmost of these, consisting of two parallel ridges, running from north-east to south-west, from 40 to 44 degrees E. longitude, is Djebel Shomer. The more southerly range, Djebel Jowryk, separated from the former by a narrow belt of desert, and running crescent-shaped from north by south to west, occupies more than four times the extent of the first, and forms the backbone of Arabia.

According to Mr. Palgrave, the northerly portion of central Arabia comprises a population of 450,000 souls, of whom two-thirds are settled, while the rest are nomads.

Several tracts in the very centre of Africa consist also of low plains. Through these pass the waters that drain into the interior from the coast ranges, and afterwards issue in one large stream, much of which, however, is lost before it reaches the Indian Ocean. The whole of central Africa, south of the tropics, may be described as an outer line or belt of very high lands, and an inner arena of low plain. In this respect Africa differs essentially from all the other large tracts of land, except Australia.

North America has very extensive low plains, under the name of prairies or savannahs. These occupy in all about 2½ millions of square miles, and have been divided into three classes, extremely different in climate, in general aspect and in productions. The varieties are (1), heathy or bushy plains; (2), dry or rolling prairies, chiefly grassy, and often very extensive; and (3), alluvial or wet prairie, abounding in pools and frequented by the gigantic deer and by wild horses. Among these are extensive plains, once occupied entirely by forest vegetation,—but these have been greatly reduced in all accessible places. Vast tracts of sand covered with pine, called *pine-barrens*, occur on the south-eastern side of the continent. The wide spread of savannahs on the banks of the Mississippi are covered with long grass in the north and with a few trees in the south, wherever the deep black soil is not taken advantage of for profitable cultivation. The expanse to the west of these savannahs is unfit for cultivation. and is called the American desert. It is crossed by the upper waters of all the great feeders of the Arkansas and the Missouri, both of which belong to the Mississippi.

In the north the shores of Hudson's Bay to a distance varying from 200 to 700 miles are all low lands, and form the great northern plains of America, which correspond with the northern plains of Asia. Thus, the northern hemisphere contains a vast preponderance of low flat lands towards the pole. whose general level is less than 500 feet above the sea. These are rarely interrupted in any way, either by hills or plateaux, and they are watered by innumerable streams, often enlarging into pools and small lakes. The streams often disappear in an almost insensible manner, being lost beneath shoals and sands, that sometimes seem to have been recently covered with water, but that are more frequently in the way of being converted into similar swamps to those already existing in this part of the world.

South America is pre-eminently a land of plains. Of these the *Llanos* of the Orinoco and the Amazons in the north, and the *Pampas* of Brazil, Buenos Ayres and Patagonia, are equally marvellous for their extent, their condition, and their products. Each requires some little description to familiarise the reader with the various phenomena.

Of the Llanos there are two kinds: the Silvas or forest plains and the Llanos proper, which are entirely destitute of trees. Parts of the latter are called the *Llanos Altos*, and form a very low barren plateau, but the greater portion are grassy.

The *Silvas* are those portions of the plains watered by the Amazons that are occupied exclusively by forest trees. There is more than a million of square miles of such country, of which at least a fifth part is annually inundated. The whole is covered with thick wood, interpenetrated by innumerable creeping and trailing plants. The forest comes down to the water's edge, and, owing to the amount of rain-fall, which is excessive, the intense tropical heat, and an inconceivably rich soil, derived largely from decomposed vegetation, the conditions of life are favourable in the highest degree for certain kinds of plants and some animals, but quite unfavourable for the presence of man. The native Indians, very few in number, are sunk in the lowest barbarism, and, hitherto, it has been found impossible to establish settlements of importance by white men, although the river is navigable and there are many extremely valuable products growing abundantly in the forests.

The "Llanos proper" commence on the banks of the Orinoco, where that stream connects by a natural canal with the Rio Negro of the Amazons. The width gradually increases towards the Gulf of Mexico, and in this part they occupy nearly 350,000 square miles. A very small part of the delta of the Orinoco is wooded, but the rest is only covered with occasional growth. The whole lies between the equator and the tenth parallel of north latitude, and corresponds exactly in position with the Silvas, which lie between the equator and the tenth parallel of south latitude. The conditions are, however, somewhat different. The banks of the Orinoco rise gently towards the interior, but only at the rate of five feet in a mile. At the distance of a hundred miles from the river, and at an elevation of 500 feet, there is a succession of low banks about six feet above the slope, and these extend for a considerable distance, forming a sandy terrace upon open limestone rock, generally barren, but bearing some grasses and supplying water to the plains below. This barren and comparatively small part of the Llanos is called the "Llanos Altos," and occupy the northernmost portion of the South American coast.

The larger and more level Llanos lie along the base of the rocky elevations, which commence with the chain of the Andes and extend from the equator to latitude 9° N. Though more distant from the ocean, these are lower than the portions just described. They commence at an elevation of 224 feet above the sea, and only rise to 500 feet as a maximum. They are so nearly level that the currents of the rivers crossing them are imperceptible, and the waters of each are sent back towards their sources by strong winds or by the occasional floods. In these plains there are no stones or rocks, not even a pebble to be seen, and in this respect they agree with the Steppes of Little Russia and Tartary. There are, also, no inequalities except some low hills of sand rising a few yards above the common level, and some slightly elevated grounds, having an area of about a hundred square miles, only discoverable by a practised eye, and whose surface is also perfectly level. The rock is a mixture of sand and calcareous rock, but is covered with mould. Grass grows freely upon it, but there are neither trees nor bushes, except a few isolated palm trees at great distances apart, and a few bushes on the banks of the streams. They singularly resemble in this the conditions of the European low lands, but have received less modification from the hands of man.

The *Pampas* are treeless plains, extending from about 20° S. latitude into Patagonia, occupying a total length of more than 2,000 miles. The breadth varies greatly, but is in few places less than 500 miles, and sometimes more. The area included is not less than a million of square miles. Commencing within the tropics, and reaching to the 46th degree of south latitnde, these plains stretch across the greater part of the south temperate zone, and are thus exposed to much variety of climate. The northern part is crossed by the tributaries of the Plata, but to the south of Buenos Ayres the rivers are fewer and smaller.

The north-western Pampas consist of slightly-undulating and dry plains, covered with luxuriant grass, and having occasionally enormous tracts occupied by thistles, which grow to the height of eight or ten feet, and which are useful as fuel. Beyond these, to the west, is an extensive pastoral district, and still beyond an agricultural district. The surface of the former is almost everywhere a dead level, but large, shallow salt lakes occur in depressions of no great depth. One of these lakes measures 50 miles in length by 20 miles in width, but the others are smaller. The soil is good, consisting of a dark friable mould, without pebbles. There is no growth of trees, and no permanent water-courses irrigate the soil. This part of the Pampas affords admirable feeding ground for horses and cattle, which were introduced by the Spaniards, and have replaced the llama, which was the indigenous ruminant of the South American plains. It has been estimated that a million of wild cattle and three million horses are fed on these plains.

The agricultural district is less level than the pastoral, the soil consisting of loose sand impregnated with saline matter, and being quite unfitted for the growth of the grasses. When irrigated, however, it becomes fertile, and is well adapted for fruit trees. Towards the north these lands pass into a salt desert, which is a wide plain reaching northwards about 150 miles, and having a breadth of about 200 miles. The whole of this is level and smooth as a floor, and is snow-white with salt incrustations. Little rain falls, dews are unknown, and the treeless and shrubless waste is broken only by a few stunted and leafless bushes.

South of the river Salado the land consists of a number of step-like terraces, running north and south, each slightly rising to the south and west. These steps are generally sterile, but sometimes covered with verdure, especially in the months which in that latitude are spring. The surface is diversified by huge boulders, tufts of brown grass, and low bushes armed with spines. There are numerous brine lakes with white, snow-like incrustations of salt. There are also platforms of black lava, like plains of iron. In these plains there are intersecting streams, but water fails to fertilise the soil. The transitions from heat to cold are rapid in the extreme, and very great. Piercing winds also rush in hurricanes across the district. The northerly extremity forming the Pampas of Buenos Ayres are somewhat more irregular in surface, but dry. The southern part is largely occupied by swamps and lagoons, one of them having an area of more than 1,000 square miles, covered entirely by aquatic plants. These swamps are liable to be flooded by the rivers, which also inundate the plains, destroying vast numbers of cattle, but leaving behind thick beds of fertilising mud. All these Pampas, therefore, differing as they do in position, climate, soil, and surrounding circumstances, have certain characters in common connecting them with the low plains in other parts of the world, both in the great continent and in America.

Australia, in some respects, resembles Africa, in having extensive low plains in the interior of the country; but differs, inasmuch as there is but little elevated land near the sea. The exact level of many of the great table lands of Australia is not yet known, and a large extent of the vast interior may, perhaps, be sufficiently above the level of the sea to deserve being called plateaux rather than plain. Towards the south, however, there is a well-known sheet of water, called Lake Torrens, which is often nearly or quite dry. Round this, and far into the interior, is a level tract not very much above the sea level, and plains almost unbroken range to an unknown distance, rising gradually into plateaux.

There are many other low plains of smaller extent in different parts of the world. Such are the deltas, at and near the mouths of rivers; others are large level tracts, more in the interior of islands and continents; but all have the same general characters. In a very large number of the most extensive of these plains salt abounds. Either there are salt incrustations or the waters are brackish. Where this is not the case, there are often barren sands or naked rock, without soil. But where there is soil and a certain amount of moisture, either extensive forests cover the ground or there is an annual growth and succession of grasses. The saline character of the soil and water does not prevent a large amount of vegetation, but it greatly interferes with cultivation, as such districts are rarely habitable by any races of civilised man.

Among the smaller tracts of low plains, those strips which occur on the north and east coasts of South America are, perhaps, the most important. Connected with the forest plains of the Amazons and the Llanos of the Orinoco, they extend almost uninterruptedly from the mouths of the Orinoco to Rio Janeiro for about 3,000 miles; and then, with an interval of 500 miles, there is another strip, 500 miles long, to the mouth of the Plata. The breadth is rarely 150 miles, and not generally so much as 100, while in many places it is less than 50. Beyond them rise the mountain masses of Guyana towards the north, and Brazil towards the east. They are crossed by innumerable streams, running down from the mountain sides to the ocean.

As a general conclusion to this notice of hills, low plains, and table lands, it may be well to recall to the reader's attention the fact, that the most remarkable low plains are on the eastern side of South America, where the geological structure indicates modern deposits on the most gigantic scale. The low plains of the old world, only second in importance, are also chiefly the floors of seas, from which the ocean has not long receded. On the other hand, the high plains are chiefly amongst or near the great axes of elevation, both in the old and new world. They are very extensive and strongly marked, both on the north side of the great mountain chain of Asia, as in Thibet, in the desert of Gobi, in Persia, and in Arabia. They extend in a similar way from Arabia to Abyssinia. In Africa they present a new feature; and instead of forming belts on each side a lofty mountain chain, they form a wide ring, round a depression of very remarkable character. In Australia their position is similar.

In America, we see the old peculiarities recur, though in a very limited manner. There, the position of the high plains corresponds with that described as characteristic of the Iberian peninsula; not with the plateaux of Iran and Thibet. In other words, they occur within the elevated area, not on its outskirts. These plains are very small in dimensions, compared with those of Asia, but they are very lofty and very characteristic.

The plains of the earth are, beyond question, the most important portions of its surface, in reference to organic life of all kinds. They include the valleys of the principal rivers, which are, in fact, but high or low plains traversed by streams. Growing and living habitually in the valleys and on the plains, are almost all the great varieties of form of vegetable growth, almost all the insects and other land invertebrata, and most species of reptiles. The innumerable birds that people the air find habitations in the forests, or feed on the fruits of these comparatively sheltered districts, and except where the soil is only bare hard rock or loose sand, where no rain falls, or where salt incrustations cover the surface, there is always life in some form.

Many of the plains, also, are specially marked by some vegetation, or by some tribes of animals. The Asiatic plains are richer, in this respect, than the American, and the tropical plains are characterised by modes of growth different from those common in temperate latitudes. Thus the former, or Asiatic steppes, exhibit numerous flowering herbaceous plants, while in the tropics there is a tendency in all vegetation to become arborescent. In the Steppes of Little Russia, both in Europe and Asia, and in the Pampas of South America, thistles grow to such enormous magnitude, and in such abundance, that at certain seasons they overtop and exclude all other plants. In northern Europe, heaths replace all others. In the desert, the cactus alone exhibits life. In South America, the plains are, at one time, without signs of life of any kind; at another, so densely covered that it is difficult to comprehend the possibility of a change so startling, produced in so incredibly short a time as is needed for the transformation. All that is most important in life is done on the plains and in the valleys, and thus these parts of the earth need very close and careful consideration, if we would understand Nature's method in adapting the earth to the purposes of existence.

In human history, also, plains, steppes and plateaux possess their own special races. The inhabitants of the higher lands have proved effective barriers to the mixture of races, and they have poured down their hardy inhabitants to conquer and change the destinies of the peoples of the low plains. Many times in the history of the human race, have these results been known to have taken place, by the evidence of written records. How often the same result has taken place before written records existed, may be guessed at, but will never be known. "The pastoral nations of the Steppes,—Moguls, Getæ, Alani, and Usuni,—have shaken the world. As, in the course of past ages, early intellectual light has come like the cheering light of the sun from the East, so, at a later period, from the same direction, barbaric rudeness has threatened to overspread and involve Europe in darkness. A brown, pastoral race of Tukiuish or Turkish descent, the Hiong-nu, dwelling in tents of skins, inhabited the elevated Steppe of Gobi. Long terrible to the Chinese power, a part of this tribe was driven back to central Asia. The shock, or impulse thus given, passed from nation to nation, until it reached the ancient land of the Finns, near the Ural mountains. From thence, Huns, Avari, Ghazarés and various admixtures of Asiatic races broke forth. Armies of Huns appeared successively on the Volga, in Pannonia, on the Marne, and on the Po, desolating these fair and fertile fields which, since the time of Antenor, civilised men had adorned with monument after monument. Thus went forth from the Mongolian deserts a deadly blast, which withered, on Cisalpine ground, the tender, long cherished flower of art."*

---

* Humboldt's "Aspects of Nature." Sabine's Translation, p. 6.

PART THE THIRD.

WATER.

CHAPTER VII.

THE OCEAN.

So large a part of the earth's surface is covered by water—so important are all the phenomena connected with this condition—so influential is the presence of this aqueous sheet on the whole history of the globe, both ancient and modern, that everything having reference to it is interesting and valuable. We shall endeavour, in this chapter, to bring together the principal facts that have been determined with regard to the extent, form, and depth of the various oceans; the salts and other solids held in solution; the temperature of the water; and its movements. The latter may be superficial and temporary, as wind and storm waves; or affecting the whole mass and constant, as marine currents; or, lastly, affecting the whole mass, but periodical, as the tides. The great expanse of ocean includes many partially enclosed seas of very different dimensions. All are, however, connected together, and all are subject to the same general conditions and laws.

We have already, in speaking of the land,—of the form of the continents and their limiting coasts,—pointed out, in some measure, by inference, the great barriers that enclose the ocean. We must now, however, recapitulate these to indicate the form and dimensions of the tracts of water. There is really but one great ocean, covering so much of the earth as does not rise above a certain level, and the three great masses and numerous smaller tracts of land that rise above this level are the continents and islands. Owing to the position of the land, we have the water divided into two unequal parts, the Pacific Ocean and the Atlantic canal. The former is broad, open, and uninterrupted; the latter is comparatively narrow and shut in, as indicated by the name *canal* substituted for ocean.

These two bodies of water are connected by the North Polar Sea, and by a wide and open sea south of a line joining Cape Horn and the Cape of Good Hope.

The Atlantic canal, or ocean, is much smaller than the Pacific, but is far more important, as being the great highway of nations, and having on or near its shores all the most important commercial ports of the world. We may, therefore, properly commence our account with a statement of its more striking peculiarities. Extending from the Arctic circle to the icy barrier that surrounds the Antarctic continent, its length is 140 degrees of latitude, or nearly 10,000 miles; its width, between the two great continents, varies from 800 miles (between Greenland and Norway) to 1,500 miles (between Brazil and Sierra Leone), or at its widest part 3,600 miles (between Florida and the coast of Africa). It is, therefore, an irregular elongated valley, covered with water. It is enclosed by a very broken coast line, including on both sides a number of large indentations, of which the Baltic and the Mediterranean, on the eastern or European side, and Baffin's Bay, Hudson's Bay, the Gulf of Mexico, and the Caribbean Sea, on the western side, are the principal. It receives the drainage of a very large area of the land, entering partly directly, and partly indirectly, by the connected seas and bays. Of the inland seas, the Baltic is long, tortuous, and narrow, entered by very narrow straits, very shallow, and receiving a large drainage. Its water area is about 200,000 square miles. The Mediterranean, with its subordinate waters, penetrates much more deeply into the great continent than the Baltic, separating, as is well known, Europe from Africa. It occupies nearly one million of square miles, and opens into the Black Sea by the Sea of Marmora. The Black Sea again communicates with the Sea of Azof, by the narrow Straits of Kertch. The total area, covered with brackish and salt water, is not less than 1¼ millions square miles. The temperature of the water in the Mediterranean is several degrees higher than that of the Atlantic outside the Straits of Gibraltar, and its waters are salt. Many parts are extremely deep. The bed of the Mediterranean is divided into two parts by a ridge, forming shallow water between the southern extremity of Italy and Africa.

On the American side, the Gulf of Mexico and the Caribbean Sea, separated from the open Atlantic by the West Indian islands, occupy together nearly two millions of square miles.

The Caribbean Sea is much the larger; its depth is great and its waters very hot. The Gulf of Mexico is separated from it by a chain of islands. Of the northern bays and gulfs, Baffin's Bay is twice the area of the Baltic, but wider and more straight. Hudson's Bay is a little less dreary, and is also of vast dimensions. The West Indian Islands and the British Islands are the most important insular groups.

The Pacific Ocean alone covers more than half the surface of the globe, and its area is about 90 millions of square miles, between the shores of America on one side, and those of Asia and Australia on the other. Its width at the northern extremity, between East Cape, in Asia, and Cape Prince of Wales, is not more than 40 miles; but the shores rapidly diverge, till, between California and the Coast of China, the distance is 8,500 miles. Beyond this, to the south, the width remains nearly the same to the extremity of Australian land. The length of the ocean, from the Arctic to the Antarctic circle, is about 10,000 miles. The Pacific has but few large inland seas opening from it, nor does it receive the drainage of a large number of important streams. In both these respects it is inferior to the Atlantic. The Yellow Sea, the China Sea, and the Sea of Japan, are the most important of its subsidiary seas, and the rivers of China the only important rivers. Although poor in seas and rivers, this ocean contains, however, very large and important islands, as already pointed out; but the island districts are limited to certain parts, leaving a vast area altogether uninterrupted, and rarely visited. The depth of the Pacific is in parts very great.

The Indian Ocean is bounded by Asia, Africa and Australia, and by the Antarctic land. Including its important subsidiary seas, its area is about 23 millions of square miles,—almost as much as that of the Atlantic. Its seas are the Red Sea, the Persian Gulf, the Bay of Bengal, &c. It includes very important islands, and groups of islands, and receives the drainage of several of the great rivers of Asia.

The Arctic Ocean includes an area of about three millions of square miles of water, bounded by the northern coasts of Europe, Asia, and North America. It connects with the Atlantic by a wide strait between Greenland and Norway, and with the Pacific by Behring's Straits. It is, for a large part of the year, choked with ice, but there is water communication in summer, connecting the Pacific with the Atlantic. It contains some islands. There is a corresponding sea at the South Pole, but of it little is known.

Such are the great oceanic tracts, as determined from a mere superficial observation of the earth's geography; but there is a larger and more comprehensive view of the natural divisions of the surface of our globe, which we must now consider. The great areas of ocean are not only bounded by definite coast lines, but are more or less broken up by means of the oceanic islands alluded to, and by banks and shoals. These boundaries frequently form distinct basins, even where the connecting banks and submarine ridges fail to reach the surface. Each great oceanic saucer, thus formed, presents an almost continuous fringe of mountains, generally near the water line. Thus, starting from Mount Elias, on the north-eastern shores of the Pacific, there is an almost continuous chain formed by the Rocky Mountains, the mountains of Mexico and central America, the South American Andes, and Tierra del Fuego; and beyond this the line is continued towards Graham's Island, and plunges into the unknown but mountainous regions of Antarctic land.

From the same point, Mount Elias, we find an almost unbroken line of mountain along the Aleutian Archipelago continued through the peninsula of Kamtchatka, the Kurile Islands, Jesso, Japan, and the Philippines. It may thence be followed by the north of New Guinea and New Britain, the Salomon Isles, the New Hebrides and New Zealand, and so to the Antarctic continent, forming an almost uninterrupted belt round the vast circuit of the Pacific. But within this basin are many smaller basins. One from Japan, by the Ladrone Islands to New Ireland, is nearly half the area of Africa. Another, but much less clearly-defined line of submarine mountains, connected by structure, and rising occasionally above the water level in volcanic peaks, commences about mid way between the New Hebrides and New Zealand, and passing first towards the north to the Friendly Islands and Navigator group, runs eastward across the Pacific, being indicated in the Society Islands, Marquesas, and Gallapagos group, and connecting with the great chain of the Andes on the line of the equator. Thus, if the bottom of this ocean were elevated a comparatively small amount, the Pacific would be divided into a northern and southern basin; the northern being again subdivided by a line running northwards from the Society Islands through the Sandwich Islands and the northern coasts; while the southern is again subdivided by a line commencing from the Society Islands, and, ranging nearly eastwards, through Easter Isle and Juan Fernandez, to the Chilian Andes. On all these lines volcanoes exist. Lastly, it would seem that a further dividing line may extend from the Sandwich Islands, eastwards, through the volcanic island of Revillegigedo, to the mountains, or rather to the fissure between the mountain chains, crossing central America from west to east.

The Atlantic Ocean is similarly broken up, and the sub-basins are very distinctly traced. The elevated rim of its northern basin may be thus defined. Starting from Iceland on the east side, and proceeding southwards, we find the Faroe islands, the mountains of Scotland, Wales and France, the western Pyrenees, the coast of Portugal and Spain, the Atlas, and the Azores. From this point, a multiplicity of shoals and banks, crossing the ocean and terminating with the great bank of Newfoundland, form a depressed rim. In this way we find an almost continuous chain of mountain land, either sub-aerial or sub-marine, reaching finally to Greenland and returning to Iceland. This forms the northern Atlantic Basin. The central Atlantic is equally marked as an oceanic basin. Commencing with the bounding line of sub-marine highlands between Newfoundland and the Azores, and thence continuing through Madeira to the Canary Islands and the Cape de Verdes, we advance westwards by the island of Fernando Noronho to Cape St. Roque. This forms a second well-marked basin. The southern Atlantic is subdivided by a ridge through South Ascension, North Ascension. St. Helena, and so on as far as Cape Negro, on the west coast of Africa, and thence by land to the Cape of Good Hope. Thence turning westwards we reach Tristan d'Acunha, and still beyond to the south-west we reach the isle of Georgia (55° S.), and so advance by the Falkland Islands to the volcanoes of Tierra del Fuego. These basins are not perfectly defined, and they are by no means complete, but they are so far indicated as to mark them as great outlines of the earth's skeleton form, determined by causes that have governed the production of that form from an early period.

Besides these basins of the Great Ocean there are many others more or less distinctly defined. Many of them are known under the name of seas, but are independent, so far as the possession of a distinct basin-rim can make them so. The Caribbean Sea and the Gulf of Mexico form such basins. The Mediterranean is another, and the Baltic another. The bounding outlines of these seas are well known. The Bay of Bengal is not less remarkable. The Chinese and Malayan Seas, containing within them the important island of Borneo, the seas of Okhotsk, of Kamtschatka, of Japan, and the Arabian Sea, are less known. They all deserve careful consideration as to details, being the principal examples of enclosed, or nearly enclosed, areas permanently occupied by salt water, to which the name *basin* is properly applied. A knowledge of their details will help us to understand the physical configuration of that part of the surface of the globe which is now under water, and which, therefore, forms part of the oceanic area.

It is evident that a knowledge of the ocean floor is necessary to enable us to obtain a correct notion of the physical geography of the divisions and sub-divisions here alluded to, and this knowledge, as may be supposed, is not very easy to obtain. The depth of water and the nature of the bottom have been determined of late, not only with a great approach to accuracy in special observations, but so systematically, and at such small intervals in some parts of some seas, that we are able to obtain facts enough to justify general conclusions. It is to be desired that such measurements should be made on a larger scale, and that no ship should omit taking soundings whenever circumstances will admit. Every fact of this kind is useful to science.

The old methods of sounding at sea in deep water were extremely tedious and very doubtful. A heavy lead was dropped, and as much line run out as seemed required. No account was taken of the drift, and in great depths it was difficult to be sure when the lead touched the bottom. In drawing it back, even if the lead was brought up, the only knowledge it gave of the bottom was from the few grains of mud or a few stones adhering to a lump of tallow in a hollow beneath the lead. Sometimes the marks left on the tallow suggested that the bottom was hard rock, and not mud. We owe to American perseverance and ingenuity the first successful attempts to reach the bottom and record the true depth and nature of the bottom in really deep water. After many trials and running out line, sometimes more than 10 miles in length, it has been found that no parts of the Atlantic or Pacific in which the depth has been measured by the new method are really much deeper than from 30,000 to 40,000 feet, which is not greatly more than the height of the loftiest summits of the land above the sea level. In fact, it would almost seem that the greatest depths of ocean may bear the same proportion to the loftiest mountain peaks that the area of the sea does to that of the land.

Deep-sea soundings, as at present carried on in the British Navy, require a heavy weight of a hundred pounds or more, sliding on an iron shaft, terminating with a strong clamp or drag which opens when the bottom is reached, and closes by a spring the instant the apparatus is lifted. The weight is so contrived as to drop off when the bottom is reached, so that the line is drawn up with the clamp, but without the weight. In deep soundings this is indispensable, as the friction in lifting even the line alone, without any weight, is so great as to require the full strength of a steam-engine winding it on a reel. The nature of the bottom is determined by the fragments brought up; and by a dredge invented by Dr. Wallich, and occasionally used in the soundings of the Atlantic, several pounds weight were obtained of whatever material is present. Almost everywhere, however, the floor of the Atlantic has been found to be covered by a peculiar soft, mealy, sticky substance, called *oaze* by the marine surveyors. On careful microscopic examination this is found to be an impalpable powder, for the most part of carbonate of lime, nine-tenths of it consisting of minute animal organisms, about 5 per cent. of angular fragments of some hard mineral, and the rest flinty skeletons of animals and plants of the lowest and simplest structures. Occasionally, however, fragments of larger shells, and even living star fishes have been obtained. The adhesiveness of the oaze is the result of the pressure of the heavy column of water above it.

The floor of the Atlantic Ocean, as determined by deep soundings, consists of a series of descending steps, not very closely resembling the form of any of the larger tracts of land now above the sea, but having more resemblance to Africa than Europe, Asia, or America. Very broad and comparatively level terraces extend for a certain distance beyond the existing shores, and are succeeded by steep cliffs dropping some 9,000 feet. For a distance of 230 miles from the coast of Ireland there is a slope of only about six feet in a mile, little more than one in a thousand. In the next 20 miles there is a fall of 9,000 feet, after which for 1,200 miles there seems little disturbance of level. This vast terrace is one of several that appear to characterise the bottom of the great Atlantic canal. By a succession of drops we at length attain the greatest depth—about 30,000 feet—which is on the American side of the ocean, some distance south of the great bank of Newfoundland, and between the 30th and 40th parallels of latitude. At this depth there is a basin-shaped depression nearly 1,000 miles in length.

Of the bottom of the Pacific much less is known. The depth of that ocean, as we have already remarked, seems to bear some proportion to its very large dimensions as an open sea. The depth of 40,000 feet has been attained by soundings, but the outline of the bottom of this great basin is not yet even approximately ascertained. The inland seas of the Pacific are either shallow or their condition as deep clefts is indicated by the form of the land immediately adjacent. The Indian Ocean is little known by soundings.

Sea water is both salt and bitter. In all parts of the ocean the water holds in solution a certain quantity of solid material, of which by far the largest part consists of chloride of sodium or common salt. Much has been said as to the cause of this condition of so large a part of the water on the globe, and certainly to very little purpose. It would be as reasonable and profitable to inquire why silica, and alumina, and lime, constitute the important bases of all soils and rocks as to seek to discover a reason for the saltness of the ocean. No doubt it is an adaptation full of uses and full of meanings, but what in the whole economy of nature is not so? It seems almost impertinent to single out one contrivance of nature, if it can so be called, and magnify it as a special interposition of Providence. That the water of the sea is salt because it would otherwise putrefy, is contradicted by daily experience in every country where there are large lakes, or that being salt it freezes less readily than if it were fresh, not expanding at the freezing point of fresh water:—these are facts which really prove no more than that all created things are mutually adapted; but this is equally proved by every other fact in nature.

The quantity of salt in the ocean is not absolutely the same in all parts, or at all depths. It varies also in the different closed seas, according to the amount of fresh water received into them from rivers, and the rate of evaporation from the surface. Some are salter, others less salt than the ocean. Where great rivers empty themselves into the ocean, the water is less salt for a vast distance from the shore. In general, the Atlantic is more salt than the Pacific;—the water of the ocean in the southern hemisphere is also generally more salt than that in the northern. In the Pacific, which is the great open ocean, the salt is in largest proportion in a belt between 22° N. and 17° S. latitude, while about the equator the water is somewhat fresher. Near the Polar seas the proportion of salt is smaller, owing, no doubt, to the melting of the ice at certain seasons.

Generally, the proportion of solid matter in the ocean is about 34·4 parts in a thousand, and the ingredients are very numerous, although a very large proportion of the whole are only present as traces, or in exceedingly minute quantities. Those which are tolerably abundant are neutral salts, consisting of chlorides of sodium and magnesium, sulphate of soda, carbonate of lime, and silica. Of all the known elementary substances, thirty-one have been detected in sea water, and the number will probably be increased by the careful application of the method of spectral analysis. The following are the names of the elements as given by Dr. Forchhammer. (Proc. Roy. Soc., vol. xii. p. 129.) Oxygen gas and nitrogen gas, as atmospheric air, and nitrogen in ammonia, carbon (in carbonic acid,) chlorine, bromine, iodine (in fucoids), fluorine (in combination with calcium), sulphur (in sulphuric acid), phosphorus (as phosphoric acid), silicium (as silica), boron (as boracic acid), silver (in some seaweeds), copper (in marine animals and plants), zinc (in marine plants), cobalt and nickel (also in marine plants), iron, manganese, aluminium, magnesium, calcium, strontium and barium (as sulphates in fucoid plants), sodium and potassium, lithium, rubidium, cæsium, and arsenic.

In particular seas, and parts of seas, the specific gravity or density of the sea water differs somewhat considerably. In the North Atlantic Ocean, from the equator to latitude 50°, the mean of a large number of observations shows a specific gravity of 1·02664; while that of the South Atlantic, within the same limits, is 1·02676, showing an excess of ·00012. If we take the limits 30° north and south, the mean densities are 1·0267 and 1·0271, the difference being due to the large influx of fresh water from the Plata, between 30° and 50° S. The chief cause of this difference is to be sought for between the equator and latitude 10° N., in the belt of equatorial calms and rains. In temperature there is a marked difference, the South Atlantic being decidedly colder than the North, by nearly five degrees; and it is a difference tolerably uniform, parallel for parallel. The specific gravity of sea water is greatly affected for a time by heavy rains. This time may extend to more than twenty-four hours.

The specific gravity of the South Pacific also exceeds that of the northern part of the same ocean, but both are somewhat below those of the corresponding parts of the Atlantic. The mean of the North Pacific is 1·02548, and of the South Pacific 1·02658. The same is the case with the temperature, the mean temperature being as follows:—North Atlantic 71·56° F., North Pacific 69·94° F.; South Atlantic 66·66° F., South Pacific 67·70° F. It is possible that the middle part of the Pacific may be more dense than those parts where the observations have been chiefly made.

The Indian Ocean is both of less specific gravity and warmer than the Pacific. The mean specific gravity of the part south of the equator is 1·0263, and its mean temperature 69·28°. The water of the Red Sea has a mean density of 1·0286. The maximum is 1·0321 in the Bay of Suez, the minimum 1·0252 near Aden. The whole of the northern part is more salt than the southern. The mean temperature of the Red Sea is 79·3°. Above latitude 20° it is 77·4°, and below it is 81·5°. The highest temperature recorded is 95°.

Of other inland seas the Mediterranean, perhaps, is the most important. The mean of six hundred observations shows the specific gravity to be 1·0289, or sensibly greater than any part of the open ocean, and even greater than the Red Sea. The density increases from west to east. Thus, west of longitude 10° the density is 1·0286, and between 10° E. and 30° E. the mean is 1·0291. The average temperature is 67·3°; the highest 79° and the lowest 53°. On entering the Dardanelles the density decreases from 1·0278 to 1·0162. The mean of all observations in the Black Sea shows an average density of only 1·0143, while in some parts it is not more than 1·0114. These observations are of course made on water from the open sea, as, off the mouths of the great rivers the water is nearly fresh.

The North Sea differs little from the Atlantic in the density of its waters, the mean being 1·0261; but the Baltic is much lower, the mean being 1·0086, the maximum 1·0232, and the minimum only 1·0003. That it was not always so is certain, inasmuch as the shores of the Baltic are covered in some places with the shells of animals that served as food for the ancient inhabitants, and these shells certainly could not have attained the size we find them in brackish water. The diminution of salt in this sea is due to the elevation of the sea bottom, and thus to a diminished quantity of sea water contained in it, the influx of fresh water by rivers remaining unaltered.

Returning now to the contents of sea water, it is well known that common salt (chloride of sodium) is the most abundant ingredient. Nearly twenty-four of the 34·4 parts in a thousand are thus composed. Of the rest, there are about 4 parts of chloride of magnesium and nearly as much sulphate of soda. One part in a thousand consists of carbonate of lime, and only ·25, or one part in four thousand is silica. These general proportions are subject to a certain amount of local variation, but they are sufficiently near to give a correct idea of the constitution of the ocean. Notwithstanding the small proportion of silica it will give some idea of the vastness of the whole subject, to point out that the estimated total quantity of silica dissolved in the ocean cannot be less than one hundred millions of millions of tons. In the Black Sea the proportion of chloride of sodium, or common salt, in the water, appears to be much larger, and of chloride of magnesium, much smaller than in the open ocean.

There is always a certain quantity of gas present in water, besides atmospheric air. Of such gas, carbonic acid gas is the principal, and its proportion, though not large, increases with the depth. Ammonia is present, but the quantity is very small. The atmospheric air is absolutely necessary to the existence of life; and it is known by actual observation, that the greatest depths yet proved in the ocean are not incompatible with the life of animals somewhat highly organised. Great chemical changes must go on in water, in connection with the constant succession of life and the forces thus set free.

The specific gravity of water increases as the temperature diminishes, the solid contents remaining the same. But this diminution has a limit, and this limit has an important reference to the contents of the water. Thus, while fresh water attains its greatest density about the temperature of 39° F., and freezes or becomes solid at 32°, sea water continues to become heavier till the temperature is reduced to 28½. Expansion takes place on freezing; but water, like other substances, parts with its impurities when it crystallises. Thus ice, in whatever water it is formed, is always fresh.

A very pretty and simple experiment, mentioned by Capt. Maury, well illustrates the working of this law. He tells us that he filled a tall jar with sea water, placed in the water a thermometer, and a small float or specific-gravity bottle, and exposed the whole on a cold day to the temperature of 23°. "As the thermometer in the jar fell, the specific-gravity bottle rose higher and higher, showing that the water, as it cooled, was contracting and becoming heavier and heavier. This went on till the thermometer in the jar marked 27°. Then there commenced in it the display of the most exquisitely-beautiful phenomena;—fascicles of ice first formed at the bottom of the jar, and as fast as they formed they ascended to the top with great rapidity; indeed it was a perfect snow storm in miniature, but turned upside down. The flakes had the appearance of falling *up*. As soon as they began to form, the thermometer in the jar rose to 28°, and there remained as long as the little storm continued."* Had the water been fresh, the temperature would have been lowered gradually to 39°, the specific-gravity bottle showing descending currents of colder and heavier water till that temperature was obtained. On further cooling, the lower strata of the water would have changed slowly in temperature and density, but the upper strata would have become gradually lighter till a coat of ice formed on the surface at 32°, or a little below. After that, the ice would thicken very slowly and the body of the water remain almost unchanged, as ice conducts heat very slowly. The general result is, that in large quantities of fresh water exposed to a cold atmosphere there is little circulation of the water, in consequence of the continuance of surface cold, even to a point much below the freezing point; and thus the temperature of the water below is kept up during the longest and severest winters; but on the other hand, the surface is soon a sheet of ice, and cools the surrounding air. In the ocean, the surface is never frozen in sheets, except within the Arctic and Antarctic circle, and then, perhaps, only because of the vicinity of land. A constant circulation is kept up throughout the whole body of the water,—the warm water from a distance is brought in to supply the place of the chilled water at the surface in high latitudes, and thus there are currents produced whose influence is very widely felt.

---

* Maury's "Physical Geography for Schools," &c., p. 85.

The temperature of the waters of the ocean is far more slowly affected by the action of the sun's rays than that of the dry land, but on the whole the effect of the existing combination of circumstances is, that in most parts of the ocean the surface waters are warmer than the water below, which gradually becomes cooler and denser as the depth increases. This is the case in all temperate and tropical parts of the ocean, and even under the equator. The cooling, however, only continues to a certain depth. The temperature thus reached is 39½° F., the point at which water attains its greatest density. The diminution of temperature goes on at a very different rate in different seas, the thermometer sometimes showing a difference of one degree for seven, and sometimes for fourteen fathoms of depth. The depth of the stratum of invariable temperature and greatest density is greatest under the equator, where it amounts to 1,200 fathoms. It gradually lessens, until in very high latitudes, both north and south, it reaches the surface. Within this limit, and close to the poles, the water is warmer below than above the surface. Although, however, the position of this stratum is constant, or very nearly so, the water above and below it is always in a state of movement, and it is in fact this incessant movement up and down that distributes and regulates the heat and cold producing a perfect and uniform system of order out of innumerable irregularities.

The pressure of superincumbent water on the bottom of the ocean, and on all substances contained in it at great depth, is of course in proportion to the depth. The result is seen in the condition of the mud at the bottom which, when brought up from great depths, is compact and tenacious, and altogether different from the state it assumes when relieved for some time from pressure. It is seen still more clearly when rope, wood, or other compressible material is carried to the bottom and brought up again. Thus wood, sunk to great depths, becomes water-logged, and very much more dense than it was before. Rope has all the tar squeezed out of it, and comes up in a state almost unrecognisable. A bottle filled with salt water, and very tightly corked, has its cork forced into the bottle. In spite of this, animal life exists in the greatest attained depths, and whales seem capable of descending at will to some miles below the surface. Star fishes were brought up alive from the bottom at a depth of 1,260 fathoms by Dr. Wallich, and minute foraminifers, and other very simple forms of organic life, are able at all depths to separate the materials that form a large proportion of the fine mud at the bottom of the Atlantic and Pacific Oceans. Wherever the sun's rays can penetrate there is life, and in these depths of the sea there is air as well as light.

The colour of sea water, when seen under favourable circumstances, is exquisitely beautiful, and the water itself is limpid and transparent in the extreme. It is quite possible under a vertical sun to see distinctly the bed of the sea, and all that is going on between the surface and the bottom, in depths of 80 or even 100 fathoms, and even in the Arctic Ocean, where the sun is never high, shells and other objects have been seen in 80 fathom water. The colour varies with the state of the atmosphere, but is always of the same rich ultra-marine when seen under the most favourable circumstances. This, also, is the colour of the light transmitted through a considerable depth of water, and reflected back from a white bottom into the celebrated 'Blue grotto' at Capri, in the Bay of Naples. This cavern affords one of the best instances known in which the colour of the water is separated from all other tints derived from the atmosphere. The cause of this colour is not ascertained with certainty, but observation with distilled water would seem to prove that is the real colour of pure water. It has been supposed to be derived from metallic oxides, for copper is known to be present in salt water with many other metallic elements, but this is hardly probable. Changes of weather are very rapidly and distinctly indicated by the colour of the sea water. These may be due to the movements of minute animal organisms, which abound in all seas, and are the food of many large fishes, and of whales, or they may be produced by changes in the state of the atmosphere. In certain seas there are local peculiarities of colour. Thus the sea is red or vermilion in consequence of animalcules contained in it in the Red Sea, the Vermilion Sea, off California, and the mouth of the River Plate. The Persian Gulf and the waters of the Arabian coast are often green, and the waters of the Arctic Ocean are olive green. The sea is white in the Gulf of Guinea, intensely black in the Black Sea and in the ocean round the Maldives, and yellow from mud in the Yellow Sea.

In the seas here mentioned that have received special names referring to colour the colour is sometimes, no doubt, an accident, and due to the presence of foreign bodies. This is not always the case. Thus the Black Sea, whose name has sometimes been described as owing to the badness of the weather during winter, has a most decidedly black or intensely dark purple colour, far away from the coast, and in perfectly clear, calm weather. The Author has observed this on two or three occasions, once near Odessa, and afterwards in the eastern part of the sea. On both these, and at other times, the circumstances of the weather were unusually favourable for observing the true colour. Besides absolute colour there are numerous other changes of appearance due to conditions of the atmosphere, and changing with every cloud. Currents of water crossing, meeting, or passing, are generally indicated by differences of colour, and streaks of coloured water are not unusual near shore, owing in most cases to the weeds or sands at the bottom of shallow water

The great body of water in the ocean is never still. Not only is the surface constantly agitated by the wind, but the whole mass is in a state of incessant circulation, partly by tidal action and partly by these numerous currents that appear to convey the water in a series of irregular curves throughout the whole world. To understand the importance of these it is necessary to consider them in some detail, and we commence with an outline of the course of the great tidal wave, which is one of the most important phenomena of the ocean, and one which very strikingly shows the mutual dependence of the various parts of our solar system. A few words on the various kinds of waves will serve to introduce this subject, and it is very necessary that the student of physical geography should clearly understand what is meant when speaking of phenomena so large and so influential.

When standing on the shore, we watch the motions of a vessel in the tide-way, approaching or departing from some port, or in a channel between two seas, after weather moderately calm but succeeding a storm, we may notice a variety of movements of the water altogether independent, and all going on together. The vessel will be rocked more or less violently by large waves, and innumerable smaller waves or ripples will break against its sides. At the same time it will be drifted in or out of the harbour, or in some definite direction, according to the set of the tide or current. But the storm-wave and the ripple are mere undulations of the surface while tides and currents are movements of the whole body of water, or of part of it limited in some definite manner. The former have no tendency to move the ship forwards or backwards—some of the latter are waves of translation, and really do move it one way or another. Of the two the tide-wave is in ordinary cases a movement of the water, advancing for some hours and then receding for a somewhat longer time, and the advance and recession are nearly of the same amount, and occur twice in every twenty-four hours. A current is a portion of the water, including either the whole depth or only part of the depth, moving steadily onwards along a certain course, varied occasionally by local accidents, but dependent chiefly on the general relations of land, water, and temperature, and therefore only changing with changes in the physical configuration of the globe.

The origin of wind-waves is easily understood. They are due to the friction of currents of air, however produced, on the surface of large sheets of water. This friction drags along the surface of the water, and produces parallel ridges at right angles to the direction of the wind. Where the wind blows steadily for a long time with some force parallel to the surface, a continuous but shallow current may be produced without disturbance, and this cause is capable of originating some of the currents that cross the ocean. Where the wind varies from time to time, both in force and direction, and where it impinges on the water at any angle, the particles of water are lifted into minute waves, each of which, by means of its ridge, protects the water beyond it from the wind. The wind is thus forced to impinge on the surface a small distance beyond. As the wind continues, these waves increase in number and magnitude. As the force increases, the agitation, which at first was confined to the surface, sinks deeper and deeper, and the waves rise higher and higher, breaking at last in foam over the hollow between two that are adjacent. Owing to the irregular action of the wind which, during severe storms, blows in gusts of great violence, and frequently changes in direction, and owing also to the fact that storm-winds are invariably accompanied by occasional lulls, the waves become confused and broken. They soon overtake each other, and thus at length form those sublime and awful seas, only attained in open ocean and deep water. The highest and largest waves do not often exceed 40 feet from the crest to the deepest part of the trough. The uninterrupted length of a wave of this magnitude is not very considerable. When these great waves approach the shore or shoal water and reach the bottom of the sea they increase in height, reaching sometimes to upwards of 150 feet, but they diminish in breadth or amplitude, and become pointed. Thus lifted up they often topple over, breaking with great violence into foam. It is not likely that the extreme effect of storm-waves in deep water disturb the water at a greater depth than 300 feet. After such great waves have been formed the result is shown by a deep heaving of the mass of the water, called a ground swell, which is often propagated through the water to an enormous distance, terminating only where the undulation is stopped by the resistance of land, and by it thrown back. In this way is caused the generally broken water of the Bay of Biscay and the Gulf of Lyons. In the South Pacific Ocean these billows or smooth waves, proceeding from quarters quite independent of the wind or marine currents, sometimes travel more than 1,000 miles. They are ultimately converted into surf or broken water on the banks of the coral islands in the great southern archipelago.

The mechanical force of storm-waves is very great, and is jointly due to their mass and velocity. During storms, the pressure of large waves on the west coast of Scotland, coming in from the Atlantic, was estimated by Mr. Stevenson at upwards of 6,000 pounds on the square foot. This is fully ten times the mean pressure of the waves during summer.

The tidal-wave has an origin altogether independent of the wind. The whole mass of the earth, the fluid and gaseous parts of it as well as the solid, are, as we have seen, attracted by the sun and moon, in proportion to their mass, and the solid earth, the ocean, and the atmosphere are separately attracted, because they are in distinct mechanical conditions. Thus the moon draws out of its course and towards itself, to the point at any moment subject to its influence, a part of the water of the ocean, and it will also draw the earth away from the waters at the point diametrically opposite. There will thus be two points at which high water will exist. There will also be two points between these, whence the water will have been chiefly removed. These are the points of low water. A small swelling of the water is thus constantly following the apparent position of the moon, and the same takes place, though to a less extent, owing to its enormously greater distance, with regard to the sun. It is usual to say that this wave is formed and travels thus, but we should rather say that such a wave would be so formed and would so travel uniformly if the whole surface of the earth were smooth, and uniformly covered by a film of water. The principal tide-wave would then follow the moon, moving, at the equator, at the rate of 1,000 miles an hour, and the summit of the wave would reach the same spot, twice daily, over all the earth. This wave would be extremely small at all times, but it would reach its maximum when the sun and moon were over or opposite the same spot at the same time, for then they would pull together; while, when the moon was in the quarter, or the sun and moon produced their effect at places 90° apart, their influence would counteract each other, and the tide would be smallest. Since, however, the land is very irregularly distributed,—since the oceans are much broken and interrupted. not only by continents and islands, but by shoals and submarine ledges separating one basin from another, the tidal-wave is greatly modified. The small and true tidal-wave would move uniformly, and at its normal rate, in water of uniform and considerable depth. The motion extends to the bottom of the ocean, and the velocity of such a wave, propagated through water of variable depth, would vary as the square of the depth. Since, therefore, the depth varies considerably, it is not surprising that, in the Pacific Ocean, although the tide at one part is almost inappreciable, it becomes, in other places, strongly marked; while in the Atlantic, so much narrower, with such broken coast lines, and so many shoals and inland seas, the tidal-wave is even larger and more complicated.

From being at the outset extremely simple, the tides, indeed, must always and everywhere be broken up, divided, nd multiplied, as they advance along the broken coast lines and narrow channels that form the mutual boundaries of sea and land. And the more complicated and intricate the coast, the narrower the ocean, and the more its bottom is interrupted by shoals and banks, the further will the tide depart from its normal type, both in amount and in the time occupied in reaching from one point to another. Thus, while in certain parts of a sea there is only one tide instead of two, in every twenty-four hours, in another sea there are three or even four tides in the same period. So, also, while in some funnel shaped channels the tide rises upwards of 50 feet, as in the Bay of Fundy, in Nova Scotia, 40 feet, as in the Bristol Channel, and 30 feet, as in some parts of the English Channel; in other seas, as in part of the German Ocean, a high water sometimes interferes with and overtakes a low water, thus extinguishing the tide altogether. A high crested wave, called a *bore*, runs up several large rivers, sometimes at particular seasons, sometimes every tide, in places where the bed of a river is encumbered with shoals. Marginal and local tides, apparently disconnected from the main oceanic tides, though really derived from them, are common; more especially on broken shores, and among the islands on the Atlantic coast. As the earth revolves, a succession of tides follow each other, and marginal tide-waves are continually given off. In the Atlantic, and in the Indian Ocean, these proceed from the south, northwards; but in the Pacific, they diverge from the equator towards the poles. The great tide-wave that advances along the shores of Europe, and impinges on the west coasts of Scotland, Ireland, and Cornwall, passing up the channel, and rounding into the North Sea, occupies nearly forty hours in its passage from the great ocean in which it originates. It makes the tour of Great Britain in about eighteen hours. The part that comes round from the north, and that part advancing up the English channel, meet a little north of the Straits of Dover, and destroy one another.

The true tidal-wave is not a stream. No doubt, in confined channels, it is converted into a wave of translation, and the body of the water is driven forwards; but in open seas it is only the motion that is transmitted, not the water. A real wave of translation, moving at the rate of far less than 1,000 miles per hour, would destroy everything with which it came in contact. Thus, a ship or a bird floating on the water is not carried forward by the tide in open ocean. It is simply lifted up and let down. The water rises from beneath it, and bears it up, and then sinks again, and the ship, or bird, sinks with it. This motion of waves has often been compared to that of the ears of corn in a field. Moving backward and forward, they seem to advance, but we know that they are all rooted to the ground. In both cases, it is the wave that moves, not the water or the corn. The strong, periodical currents, produced by the tides, are due entirely to the configuration of the land, and are strictly local.

There are two kinds of currents affecting the waters of the ocean;—some are constant and permanent,—others, temporary or periodical;—some are deep, and continue their course for thousands of miles,—others are shallow, and are soon turned and checked. The latter are drifts; the former, streams. The stream currents are of great importance to climate, and very useful to navigators. They exist in most parts of the ocean. Stream currents are usually due to prevalent, but periodical winds, and are limited to certain parts of the ocean.

The origin of these currents in the ocean, and of the great system of circulation that forms so important a feature in the history of the waters that cover three-fourths of the globe, is to be sought for in the relative position of land and water, and the general distribution of heat. The currents, therefore, that we have to consider are partly due to local and temporary causes, and of these evaporation in excess of the supply from rain, directly or indirectly, is one of the most important. Prevalent winds, narrow and enclosed seas, long lines of coast stretching from the poles towards and far beyond the equator, broken and jagged coast lines, and lines of submarine hill crossing the general direction of an ocean at right angles, these are all modifying agents affecting the continuous movements of the sea, and inducing, modifying, or checking currents. An example of the effect of evaporation in a long narrow sea is to be found in the Red Sea, whose surface is an inclined plain, owing to the enormous quantity of water removed from it into the atmosphere, and not replaced by rain or rivers. The quantity thus removed, at a moderate estimate, is half an inch per day during summer. At that season the air above and around is hot and dry, and its shores are burning sands. It is not extraordinary that in spite of a strong current that sets inwards from the Arabian Sea at the rate of nearly a mile per hour (20 miles a day), the water at the head, or northern part, is some two feet lower than at the foot. As the Red Sea is 1,000 miles long, the water entering takes fifty days to reach the head, and in doing so loses twenty-five inches of height.

But the evaporated water leaves its salt behind, and this must either accumulate and render the Red Sea brine, which it is not, or it must pass away. It can only escape by a return or outer current beneath the in-coming upper stream. Such a current is known to exist in the Mediterranean, which is also a confined sea on a much larger scale, and receiving great though insufficient supplies of fresh water. A current of the same kind, no doubt, exists also in the Red Sea. It is known by observation that the surface waters at the head of the Red Sea are salter, and therefore heavier than the surface waters at the Straits of Bab-el-Mandeb. Dr. Buish has calculated that without such under current the Red Sea would have become one mass of solid salt in the last three thousand years. Both the in-draught and the deep current outwards, well known to exist, are thus explained in the case of many partially enclosed seas. At the entrance of the Red Sea there are periodical surface currents flowing in from October to May, and out during the rest of the year.

The great currents are those which chiefly affect climate. They are the best known, partly from their real magnitude, and partly because of their use to navigators. They are not very numerous, and their course and history is, for the most part, pretty well known. Of the whole number the Gulf stream of the Atlantic is the most important. It is, however, so intimately connected with a number of other currents that to understand its course from its origin we must refer to the currents of the Indian Ocean. Strictly speaking, the Gulf stream issues from the Gulf of Mexico. It may be said to rush out thence towards the north, between Florida and the Bahamas, having at the "Narrows" of Bemini a width of 32 miles, a depth probably not less than 200 fathoms, and a velocity of nearly five miles per hour. Off Cape Hatteras the width has become 75 miles, the depth 120 fathoms, and the rate diminished to 3½ miles per hour. Further north it trends to the east, describing a curve nearly identical with the arc of a great circle, from the Narrows of Bemini to the shores of Ireland. The current touches the banks of Newfoundland, where it is intersected, as it were, by the course of the Arctic current bringing down icebergs. The width is here much greater, and the depth reduced in proportion. As it crosses the Atlantic it widens and shallows, and its rate of motion is diminished to a mile an hour. Approaching the shores of Europe it is turned southwards, and dies away, or is interfered with by other currents off the African coast. As it issues from the Straits of Florida the temperature of the water is nearly 90°, and considerably above that of the adjacent ocean. After travelling through ten degrees of latitude to the north it has still a temperature of 84°, and it parts very slowly with its heat as it crosses the Atlantic. It, therefore, brings a large supply of heat to the shores of Europe. The whole course of this remarkable current is not less than 3,000 miles, and it occupies about eighty days in its progress. Although liable to some change of direction it is, on the whole, wonderfully persistent. It is a great and wide stream of heated water, larger than all the rivers of the world together, running in a definite channel through colder water of a different colour, so that when a ship enters the stream in smooth water one may see the bows dashing the spray from the warm and dark blue waters she is entering, while the stern is still within the pale green and cold waters of the banks of Newfoundland.

The Gulf stream takes its name from the Gulf of Mexico, where it emerges from that warm sea; but we may connect it with another current, starting from the Bay of Biscay, skirting the shores of Africa, crossing the Atlantic to Cape St. Rocque, in Brazil, and entering the Caribbean Sea with a temperature of 96°. This is a portion of the Main equatorial current, first distinctly recognisable off the coast of Africa, a little south of the equator. Running nearly on the line of the equator, and therefore in a great circle to the west, it is nearly parallel to the Guinea current, which, coming from the west, dies away near the mouth of the Niger. These two adjacent streams, whose temperature differs by 10° F., thus flow with some velocity in opposite directions for nearly 1,000 miles. The Main equatorial current, after crossing the ocean to about 22° W. longitude, sends off a north-west branch to San Rocque, and another branch to the south, parallel to the South American coast. It there forms the Brazil current. It has several smaller branches, and is everywhere a cold current, generally from 4° to 6° below the adjacent ocean.

Its depth must be considerable, as the waters of the La Plata, issuing with a very strong current, do not seriously deflect it.

Connecting the Gulf stream and the Equatorial current are two. Rennel's current runs northwards along the coasts of Spain and France to Ireland, and the North African current runs southwards into the Equatorial current. Replacing the waters of the hot stream removed from the Gulf of Mexico there is a strong Arctic or Polar current coming along the coasts of Greenland and Labrador, and uniting with the current from Davis' Straits. This current is at first superficial, conveying icebergs sometimes across the Gulf stream, but it descends and runs for the most part at a considerable depth below the Gulf stream. It connects with the United States counter-current. Besides some currents in the northern part of the South Atlantic, the Antarctic current conveys into the latitude of the Cape of Good Hope, and even much higher, large icebergs from the South Polar land. The South Atlantic current is part of a stream coming round the Cape of Good Hope, and another part of the same stream forms a counter-current. Most of these currents vary in width, depth, rate, and temperature, according to season and local conditions, but the changes are kept within fixed and often narrow limits.

The currents of the Pacific are less definite, or at least less known than those of the Atlantic. In the North Pacific is a kind of Gulf stream, called the Black Stream of Japan, but it is far less definite than the Gulf stream of the North Atlantic. In the South Pacific a South polar current brings cold water along the western coast of South America, reversing the operation of the Gulf stream on Europe. In the Indian Ocean is the Mozambique current, a warm stream, running from inter-tropical seas to the polar regions, sweeping the east coast of Africa, and resolving itself into a gentle flow of warm water towards the Antarctic Ocean, and a counter current of cold water towards the north. This is Humboldt's current.

Besides the tidal wave, the waves produced by the wind, the great currents and counter-currents of the ocean, and the smaller, more partial, and less regular currents that exist in all enclosed seas, there are other phenomena of the ocean more strictly local, but requiring notice. Eddies and whirlpools are among these. They are produced by opposing winds and tides. The Maelström, on the Norway coast, is occasioned by tidal currents round certain islands. It is a mile and a-half in diameter, and its roar is sometimes heard at a distance of several leagues. It varies, however, and is sometimes trifling. The celebrated and classical vortex of Charybdis, outside the harbour of Messina, consists rather of undulating water than a true whirlpool. It is often not to be recognised, but at certain seasons it is said to be powerful enough to whirl round even a seventy-four gun ship, and is formidable to small craft. The water near is from 70 to 90 fathoms' deep, and the eddy is probably due to the meeting of currents.

There are many examples of still water surrounded with currents. Of these the *Sargassos*, or weedy seas, are the most remarkable. The North Atlantic Sargasso sea occupies a considerable but variable space between the 15th and 30th parallels of north latitude and the 20th and 40th meridians of west longitude. It is sometimes so thickly matted over with brownish weed as to hide the water, and present something of the appearance of a drowned meadow, on which one could walk. This part of the sea is crowded with fish; and into it are drifted trees and plants, brought down by the Amazon from the Andes, and from the Rocky Mountains by the Mississippi. A large deposit of organic matter must be forming at the bottom of this part of the Atlantic. Another Sargasso sea exists in the North Pacific, between the 30th and 40th parallels of latitude. It is similar, but smaller, and less rich in drifted matter. There is a third in the Indian Ocean, between the 45th and 55th parallels of south latitude, and between 50° and 80° west longitude. In all these, the Sargasso is in the middle of a pool between warm and cool currents. But the gulf weed is not confined to the open ocean. Fragments of it are broken away and drifted, and are thus brought even so far as the Straits of Dover. It is not unusual in the months of July and August to see large quantities of drifted weed, in crossing the channel between Folkestone and Boulogne. In perfectly fine, calm weather, the water is sometimes almost as much covered with vegetation in these seas as in the immediate neighbourhood of the great Sargasso sea itself.

CHAPTER VIII.

RIVERS AND RIVER SYSTEMS.

The grand phenomena of the ocean are, by the aid of the atmosphere, brought into direct relation with the whole surface of the land; and the circulation of water, with its various results, mechanical and physical, may be said to be the great fundamental cause of the actual structure and condition of the earth's surface. We shall consider, in another chapter, the mechanism involved in the production of these results, so far as the atmosphere is concerned. At present, looking only to the fact that rain falls, and that the water thus obtained circulates over the surface for a time, let us endeavour to trace its inevitable course. We see it—and every one is familiar with the phenomena—sometimes merrily coursing down a hill side, or rushing in a rapid torrent through a mountain gorge; now pouring in collected streams down wide valleys; collecting occasionally into swamps, pools, or lakes; pursuing its course onwards across great plains; occasionally rushing along in rapids, or falling in cataracts; receiving from time to time numerous tributaries; and at length approaching the ocean, carrying back to it the tribute derived from a thousand lands. At first the stream moves rapidly, but as it advances, generally diminishes so much in speed that, as it finally passes through the low plains near the end of its course, it becomes no longer able to convey along the mud and stones brought down from the upper country. These must accordingly be left behind. and are spread out in vast fan-shaped deltas, or in long, projecting tongues, advancing into the sea and encroaching on the domain of the ocean. Thus, wherever a principal stream makes a long passage over a large continent, it produces a marked effect, both on the land through which it passes and on the ocean it enters.

Rivers are very important phenomena. They open out the interiors of continents by providing navigable channels, enabling boats and ships to reach the population on their banks; they carry off waste material and decaying organic matter that would otherwise be mischievous; they provide water for the inhabitants of the towns built near them; and they yield power—advantage being taken of their continued currents to carry down to the sea rafts and barges, or turn float-wheels to grind corn. The channels in which they run act also as convenient channels for winds and currents of air. A country without permanent streams is, indeed, so little fitted for vegetation and for animal life, that it must almost be regarded as a desert; while a well-watered district permits of rapid development, and of early and complete subjugation by man.

It is not the largest rivers that are the most useful. Those of moderate proportions are often even more available, by being more manageable. Neither are the most rapid rivers those that most perfectly perform the duties devolving on them. The country with numerous streams of moderate volume, and running at a convenient rate, is that which will be on the whole most perfectly utilised by the human race.

As a matter of geographical convenience the whole surface of every tract of land, whether continent or island, may be divided into areas, each drained by some river or system of rivers. To make this division it is only necessary to take the best available map, and connect the points midway between the head waters of all the streams entering the sea, or some internal sheet of water. The smaller brooks and streamlets connect with others of larger size, and these with the main rivers. The number of the principal streams is not so great as to render this method troublesome, and the divisions of land into natural drainage, areas or river systems is often extremely useful. It is, of course, impossible to include, in such areas, the portions of the earth where the drainage, if any, is effected by small streams running directly into the ocean.

The line determining the drainage area of a river system is called the *water-shed* (*wasser-scheide*, water division) or *water-parting*. The former expression is more familiar to geographers; the latter, perhaps, more correct. It is necessary to bear in mind that the water-shed does not necessarily run along a mountain ridge, or, in other words, that river systems are not always enclosed by high lands. The main sources of each of two large streams running in opposite directions, may originate in the same ponds or swamps, through which, therefore, the water-shed must pass. Such main sources may even proceed from wide, level tracts of country, from which the rain runs off indifferently to north or south, so that one portion may ultimately join a stream running to the equator, while another may reach the Arctic sea.

It is evident that the sources of a stream need bear no proportion in magnitude or importance to the stream ultimately produced. All rivers of any magnitude are due to the running together of numerous streams, and it is often a matter rather of accident than intention, which of them, by bearing the name of the lower part, or that which enters the ocean, shall be regarded as the principal. There are a few exceptional cases, in which a stream, already large, issues from the earth at some definite point, and obtaining a name, at once preserves it till it reaches the sea. In such cases, however, the stream has acquired its volume of water from underground tributaries that have not been named, and this only because they have not been followed and made available.

It is also clear that the real sources of great rivers are generally indeterminable, and even if they could be discovered would be utterly unimportant and insignificant. It is, no doubt of the greatest importance and interest to learn the geography of the interior of Africa, to discover the water-courses that combine to form the Nile and other chief streams, to trace them to their sources, and to determine whether they are derived from a mountain chain, or plateau, or a lake, for in this way only can we learn the physical features of the country and all the facts that we require to know concerning its structure. But the mere looking at the nominal source of some one out of ten thousand of the streamlets whose waters enter the Mediterranean near Alexandria under the name of Nile is a matter of puerile curiosity rather than scientific interest. It is with the Nile as with most of the great rivers of the earth. All such rivers combine many important streams coming from very different lands. In the mountains of Abyssinia, visited by Bruce, are sources hardly less important than the great lakes more recently reached. Every traveller who makes a great and successful effort to visit a district before unvisited, deserves well of his fellow men, and should be welcomed accordingly, and in proportion to the difficulties incurred and the extent of the discoveries will be the estimate in which the traveller must be held.

One other point requires notice before considering in detail the drainage areas of the world. The great river systems are not necessarily disconnected. There are instances, rare but by no means unimportant, in which very large branches of streams, belonging to drainage areas altogether distinct, are connected by natural channels, as others are by artificial canals. Thus, in South America the Amazons connects with the Orinoco by a net work of rivers at a high level. There is no other instance known on so grand a scale. Even on a small scale they are rare. There is no confusion whatever as to the drainage areas of two streams thus connected.

It will naturally and inevitably happen that, as a greater rain-fall generally takes place on mountain sides and high ground than on low plains and in valleys, the ultimate sources of rivers will generally connect themselves with mountain chains. The fall of water from a higher to a lower level is, indeed, necessary to produce a river, for without such fall the water accumulates and becomes a swamp or lake. The actual difference of level between the original sources of a river and the sea is, however, only one and not the most important cause of its rate of advance. Streams with a moderate fall, but running with little interruption on a regular slope and in a straight course to the sea with a large body of water, are the most rapid. Those which are tortuous, either from the presence of hard rocks in their line of course or from being obliged to wind through a broad tract of low, muddy soil, are generally very slow, even if they originate at extremely high levels. The former carry the detritus they bring down from the high grounds into the sea. The latter leave it behind, and by forming deltas are continually increasing the distance they have to run before becoming lost in the ocean. All streams and all parts of every stream must be regarded as assisting in the great work of denudation—removing particles of rock and soil from the higher levels and depositing them below on the plains or at their mouths.

River systems being determined by the streams that enter the ocean, it is convenient to consider them with reference to the great tracts of water, rather than the great continents. It would be too tedious to enter into a detailed account of all the river systems in the world, but an outline of the largest, most important, and most interesting is essential for the proper comprehension of this part of our subject. There are three great sub-divisions of the water that will guide us to the first grouping of these systems, and the natural divisions of the land will then help to form smaller groups. Except as regards the British group it would be impossible to include islands in any general consideration of the great river systems, as each island possesses its own series, often as numerous as those of large continents. It is also necessary to exclude the small streams that drain at once into the ocean by short courses, and do not connect themselves with the adjacent systems. There are certain important streams entering the great lakes of the old world, and not emerging to reach the ocean. These must be considered separately. The great lakes of America and Africa connect more or less directly with the ocean.

Emptying into the Atlantic ocean and into the various smaller seas opening out from it (the Gulf of Mexico, the Mediterranean, and the Baltic), we find a list which includes a large proportion of the principal streams of the world. But the natural drainage of the land is only partially effected by these streams. It will be convenient to name them first in geographical order, beginning with the north coast of western Europe, and alluding very briefly to the intervals that occur when there is a long line of coast or a large area unaffected by and not included within the systems. It does not necessarily follow that there is unimportant drainage because the waters do not collect into large channels.

Commencing with the Scandinavian peninsula we find the whole line on the west side of the lofty mountain chain that separates Norway from Sweden entirely without any considerable stream. Even on the east side and on the shores of the Gulfs of Bohemia and Finland, although there are many lakes and small streams, there is little drainage by rivers. The vast low plains to the east, extending to the Ural mountains, are crossed by a line of water-shed, separating the drainage of the Arctic Ocean from that of the Caspian Sea. The Neva is the only important stream that flows into the Baltic. Further south the eastern shores of the Baltic receive the Niemen and the Vistula, all of comparatively small extent of drainage area, and separated only by accidents of the surface from the tributaries of the Don and Dneiper, which run into the Black Sea. The Oder succeeds, and is the last stream entering the Baltic to which we need refer. All these streams run through the flat lands of the great plain of northern Europe, and they offer little that is remarkable in their course, either in the way of scenery or geology. The Neva connects Lake Ladoga with the Gulf of Finland, and is thus a strait, almost as much as a river. Its length is 40 miles (navigable the whole distance), breadth 1,500 feet, depth 50 feet. It is estimated to drain about 90,000 square miles of country. The Niemen or Memel runs 400 miles, receiving two principal confluents, and draining about 90,000 square miles. The Vistula is a more important stream. Rising in the Carpathians and running about 530 miles, including windings, it at length enters the Baltic by several arms, after having traversed Poland and Western Prussia, and received in its course several tributaries. It drains 75,000 square miles of country. The Oder, also, rises in the Carpathians, and, after running 450 miles, enters the Lake of Stettin, after which it passes into the Baltic by three branches. It drains 50,000 square miles. These various streams, together, drain more than 250,000 square miles of northern Europe.

The streams entering the German Ocean commence with the Elbe, which rises in the Riesengebirge in Bohemia and runs more than 600 miles, including windings. It receives the Spree, Moldau, Eger, Saale and other streams. Although rising at a height of 4,500 feet above the sea, its bed in all the lower part of its course is very low, and its mouth is choked up with mud and sand. It drains 56,000 square miles. The Weser is a smaller stream, formed by the union of the Fulda and Werra near Hanover. Its total course is about 250 miles, and it drains an area of 17,500 square miles. It receives several streams, and is navigable to a great distance.

We next come to the Rhine, one of the chief of the rivers of Europe. It enters the German Ocean after a long course, taking its rise in the main chain of the Alps. This noble stream has not a direct course of much greater length than the Elbe, but it is a far more important stream. The Vorder and Hinter Rhein combine to form the Rhine, commonly so called. Both these branches proceed from glaciers more than 7,000 feet above the sea. The Rhine, after this junction, runs north to the Lake of Constance, then turns westwards and falls 80 feet on emerging at Schaffhausen. Where it passes Bâle it is still 755 feet above the sea. It then runs steadily to the north, constantly increasing by the addition of a host of important tributaries, of which the Kinzig, Neckar, Main, Lahn, Ruhr and Lippe come in from the right, and the Thur, Aar, Ille and Moselle from the left. Passing between a mountain gorge below Mayence it opens out again near Bonn and becomes very wide. After entering the Netherlands it runs through a great distance of delta and mud, brought down and deposited by the stream itself in past times. It is subject to freshets and floods. The total course of the Rhine, including windings, is estimated at 700 miles, and the area of drainage at 87,000 square miles.

The British islands grouped opposite the mouths of the Rhine present a considerable area drained by three or four rivers of some magnitude, and a number of others much smaller. They discharge their waters some into the Atlantic direct, but others into the German Ocean and the St. George's Channel. The Thames and the Severn are the largest of the English streams. The Thames takes its rise from the Cotteswolds, a range of limestone hills crossing England from south-west to north-east. The Severn rises in the Welsh mountains. Both receive many tributaries and convey much water. The Thames rises about 376 feet above the sea, runs 215 miles and drains about 6,500 square miles of country into the German Ocean. The Severn rises 1,500 feet above the sea, runs 210 miles and drains about 6,000 square miles into the Bristol Channel. The Shannon, the principal river of Ireland, rises 258 feet above the sea, runs 254 miles and drains 3,600 square miles of country into the Atlantic. Of the other rivers the Trent and the Ouse in England, the Clyde in Scotland, and the Blackwater in Ireland, are the principal.

Of the French rivers the Seine, the Loire and the Garonne, besides some of smaller size, enter the British Channel or the Bay of Biscay. The Seine and Loire rise in the middle of France, the former in the Côte d'Or the latter in the Ardêche. Both receive important and navigable tributaries. The Seine runs 414 miles and is navigable for 350. It drains 30,000 square miles. The Loire runs 530 miles and drains 45,250 square miles. It is subject to inundations which are often very destructive. It enters the Bay of Biscay by a wide estuary, and carries with it a vast quantity of mud which discolours the water to a distance of many miles from the coast. The Garonne rises in the Pyrenees, and after 300 miles receives the Dordogne and enters an estuary of 45 miles. It is thence called the Gironde. It drains 32,500 square miles.

There are no streams of importance between the Gironde and the Douro. The Landes extend on the shores of the Bay of Biscay, and the Pyrenees form a coast range on the north of Spain. The Douro runs for 400 miles, but is often nearly dry. It drains 40,000 square miles. It receives many tributaries, all of which are occasionally dry. The Tagus, the Guadiana, and the Guadalquivir, are of the same general character. They traverse the table lands of the Iberian peninsula, generally occupying wide fissures in limestone rock. The Tagus is estimated to run 540 miles, draining 29,000 square miles. The Guadiana 380 miles, draining 26,000 square miles, and the Guadalquivir 280 miles, draining 20,000 square miles. These are the principal European rivers on the Atlantic coast, and they drain in all an area that may be roughly estimated at half a million of square miles.

The Mediterranean Basin receives a large drainage, and many very important streams. On the Spanish coast is the Ebro, running 340 miles, and draining about 33,000 square miles of the limestone plateau of Spain. But little water is discharged by this or any of the streams of the peninsula. The Rhone is much more important. Rising in the Alps, it reaches the lake of Geneva, and issues from that lake as a large stream. It receives several important tributaries, of which the principal are the Ain, Saône, Ardeche, and Gard, on the right, and the Isére, Drôme, and Durance, on the left. After running a swift and powerful stream about 650 miles, it enters the upper part of the Gulf of Lyons, in the Mediterranean, by a number of mouths, and through an important delta. It drains about 37,000 square miles.

No rivers, larger than mountain streams, enter the Mediterranean from the western slopes of the Apennines, except the Arno and the Tiber, and on the eastern side there is no large stream till we reach the Po and the Adige, draining the great plains of Lombardy. The Arno runs only about 75 miles. It runs towards the west, taking its rise in some of the higher Apennines, at a level of more than 4,000 feet above the sea. It is a rapid stream. The Tiber is now a very small stream.

The Po is a noble stream running 380 miles to the east, entirely across the plains of Lombardy, and receiving large and important feeders. The Adige accompanies it, and has a course of 220 miles. The country drained by these two streams is more than 40,000 square miles in extent.

Down the coast of Dalmatia, and along the shores and islands of Greece, and thence along the coast, as far as the Dardanelles, there is no important river. Entering the channel of the Hellespont, and crossing the Sea of Marmora, we come into the Black Sea, and are there met by the Danube, which pours its waters eastwards across Europe, on the north side of the Alps, and drains a vast extent of land. This great stream rises near the lake of Constance, at an elevation of 2,850 feet above the sea. Its course is more than a thousand miles, without including windings, between its source and the Black Sea. It receives a large number of tributaries, of which the most important are, on the right, the Isar, Inn, Raab, Drave, Save, Morave, and Isker. On the left are the Altmühl, Regen, Waag, Gran, Theiss, Temes, Aluta, Sereth, and Pruth. Many of these are large streams with other important tributaries. The Danube drains upwards of 300,000 square miles of country. It separates into several branches near its mouth, and terminates in a delta of some importance.

The Dniester is a stream, rising in the Carpathians, and running 400 miles into the Black Sea, near Odessa, draining about 30,000 miles of eastern Europe. The Dneiper is a much more important stream, running through a large part of European Russia. Its length is 623 miles, in a direct line, and more than double that, if the windings be included It drains 226,000 square miles. The Don, though smaller than the Dneiper, is also an important stream, with several confluents. It enters the Sea of Azof by many mouths, and through a large delta. It runs nearly 500 miles, without including windings, and drains 224,000 square miles. The Kuban, a considerable, but little known, river, rises on the north side of the Caucasus, and receives the drainage of the higher mountains of the Caucasus, being joined by a number of tributaries. It enters the Straits of Kertch, between the Sea of Azof and the Black Sea, and the mud and detritus it brings down help much to close up the channel between the two seas. Its course is estimated at 380 miles.

No river of any importance or magnitude enters the Black

Sea along its eastern or southern shores for a distance of at least a thousand miles.

The shores of the Sea of Marmora, and of Asia Minor as far as the Isthmus of Suez, are without any streams that come from the interior, or can be regarded as draining an appreciable tract of country. The next river that we have to consider is the Great Nile, the "Father of waters" of the old world, and the stream which has a longer direct course than any other.

As now known the Nile has its principal sources among great sheets of water, permanently existing at a high level (3,000 to 4,000 feet above the sea), in the far interior of Africa, in latitude about 3½° S. It is probable that these lakes are subject to great changes of level. As the Nile enters the Mediterranean in latitude about 31½° N. the stream thus runs through 35° of latitude, or nearly 2,450 statute miles in a direct line to the north. Following the windings the distance must considerably exceed 3,000 miles. The Nile receives several very large tributaries, one of them (the Blue Nile) being an important stream, formerly regarded as the main river. It drains also a vast extent of country, perhaps a million of square miles; but it must yet be long before all the tributaries are followed to their sources, some of them, perhaps, reaching much further westwards into Central Africa than there is at present any means of determining. The Nile is to some extent a navigable river, but the navigation is interrupted by cataracts or rapids a few hundred miles above Cairo. From latitude 30° N. to latitude 31½° N. (nearly 110 miles) there is a large and very important delta, through which the Nile passes by an infinite multitude of channels into the Mediterranean. The Nile is subject to peculiar periodical floods, leaving behind them mud which fertilises the country. The waters begin to rise in June and subside in September. In Upper Egypt the amount of the rise is usually 30 feet, and in Cairo it reaches 24 feet. The cause of the flooding of the Nile is not clearly known.

There is no important stream entering the Mediterranean between the Nile and the Straits of Gibraltar. Little rain falls in North Africa, and no rivers cross the great desert The Atlas mountains are too near the Mediterranean shores to admit of any important streams being formed.

The total areas of country draining into the basin of the

Mediterranean and the great adjoining waters may be estimated roughly at about two millions of square miles, of which fully one half is in Africa, and four-fifths of the remainder enters the Black Sea. Thus a very small proportion (only about one-tenth) can be traced to the various lands of Europe south of the Alps. Most of this land is dry and very absorbent, the rain that falls upon it not running off in streams on the surface, but sinking into the rock and issuing in springs, or converted at once to the purposes of vegetation.

The rivers entering the Atlantic from the west coast of Africa are but few. The largest of all is the Niger or Quorra. Its sources are not accurately known, but it certainly has a long course, and brings down much water into the Gulf of Guinea. The Senegal, also entering the Atlantic, is a large stream, and its length of course has been estimated at 1,000 miles. It is partly navigable, and one of its branches is a large and deep stream. The Orange River or Gariep is a first-class stream in the south, and has been traced from a great distance. It receives a large tributary (the Vaal), and the two streams together are estimated to have a course of 1,000 miles. The Gambia and the Coanza are probably of nearly the same extent and area of drainage, but their courses are not accurately known.

On the western side of the Atlantic the position of the drainage areas is somewhat different. Great rivers, their direction and magnitude being determined by the physical condition of the surface, pour into the Atlantic the accumulated waters from the eastern side of the Andes, after traversing, not only the breadth, but much of the length of the continent of South America. Commencing in the south, we find that for a long distance, the land being narrow, the rivers are small. In latitude 35° S. enters the magnificent Plata, an estuary formed by the junction of the Parana and Uruguay, two parallel rivers draining by their numerous tributaries nearly a million and a quarter square miles. The estuary of the Plata is 200 miles in length, and where it opens into the Atlantic nearly 170 miles across. The waters that rush through it into the ocean can be traced 200 miles from the mouth of the estuary. The Parana branch is navigable 1,250 miles for vessels of 300 tons, and the total length of its main stream, the upper part of which is called the Paraguay, is nearly 2,000 miles from its source to the sea. The

Uruguay is shorter. The main drainage area of the Plata is to the north, both its great tributaries running south and east. Waters that enter the Plata rise within three miles of part of the system of the Amazon.

The Amazon river, with its numerous tributaries and important branches, is another of those great systems of waters that render the physical geography of the American continent so remarkable. Under various names it drains considerably more than two millions of square miles. The main stream enters the Atlantic by two principal arms, the Amazon to the north, and the Para to the south. The Amazon is certainly in many respects the largest and most important system of rivers in the world. The upper part traversing Peru is called the Marañon. When it enters Brazil it becomes the Rio Negro. The name Amazon is applied only to that part below the point where the Apurimac joins the Rio Negro. By a branch of the Rio Negro (the Casiquiare, a natural canal,) the Amazon connects with the Orinoco. The total length of one stream of the river to the sea is nearly 1,800 miles in a direct line, but, including windings, the distance is estimated at 4,000 miles. Twenty great rivers, all navigable nearly to their sources, help to fill this great channel, which runs at a medium rate of 3½ miles an hour. The tide ascends for more than 400 miles, at which distance the stream is still a mile wide. At spring tides a bore or rush of water carries up a wave 10 or 15 feet in height. The Para, the southern branch of the Amazons, receives the Tocantins, another great river. It is 40 miles wide, where it enters the sea.

Next beyond the Amazon, but at a great distance to the north, comes in the Orinoco, only inferior to the Amazon and Plata. It runs for 1,600 miles, and drains an area of 335,000 square miles, receiving tributaries, some of which are navigable for 200 miles. The tides reach about 300 miles above its mouth, and at that point the river is still four miles in width. It has a vast delta entering the sea by numerous mouths.

The Magdalena is a river running for a distance of more than 800 miles with a very rapid current, and entering the Caribbean Sea with the drainage of nearly 100,000 square miles of the north-western corner of South America. It is a noble and important stream, though the smallest of the three principal rivers of the Mexican Gulf. The Rio del Norte, sometimes called the Rio Grande, or Rio Bravo del Norte, is larger than the Magdalena. It drains an important section of North America, and its drainage area is separated from that of the Magdalena by the whole of Central America, where there are no important rivers. The Rio Grande runs for nearly 2,000 miles, having some large tributaries. It drains a quarter of a million of square miles of country, but owing to numerous rapids and shoals, and a bar at its entrance, it is not navigable for largo vessels. The waters of the Magdalena, rising almost under the equator, meet and mix with those which proceed from the Rocky Mountains, in latitude 41° north.

The great father of waters, the Mississippi, combining in one system the waters of the Missouri, the Ohio, the Arkansas and a host of other streams of great volume, enters the Gulf of Mexico not far from the mouth of the Rio Grande. The Mississippi-Missouri system alone drains a million and a half square miles, or more than one-sixth part of the area of North America. The total length of the stream, from the source of the Missouri to the Gulf of Mexico, including windings, is nearly 4,500 miles. The average descent of the water from the Missouri source to the mouth of the Mississippi is five inches per mile, but the water falls rapidly at first, leaping over many cataracts, and thus, in the latter part of its course, its bed has little depression, and it runs sluggishly, though its waters are very deep. It terminates in a considerable delta. Of the various streams that combine to form the Mississippi, the Missouri is one of the most important. It rises in the Rocky Mountains, and flows rapidly to the east and south, receiving several large tributaries chiefly from the west. At its junction with the Mississippi it is 2,600 feet across. It is navigable for 2,570 miles above its junction with the Mississippi. Its whole course to the junction is 3,100 miles, including windings.

The Ohio is another most important tributary. It is formed by the junction of the Alleghany and Monongahela rivers at Pittsburg, in Pennsylvania, and thence runs more than 1,000 miles before joining the Mississippi. It is estimated to drain 200,000 square miles of country. The Arkansas carries the drainage of 180,000 square miles, and joins its confluent after running 2,170 miles from its source in the Rocky Mountains. The Red River, another tributary of the

Mississippi, enters only 130 miles above New Orleans, after running 1,500 miles from the foot of the Rocky Mountains, near Santa Fé, in Mexico.

From the Mississippi round the south and east coast of North America there are numerous streams which in Europe would be considered large, although, compared with the vast systems just described, they seem insignificant. They include the Alabama, which, after running 560 miles from the north, is joined by the Tombigbee, which has come down about 260 miles, and then, under the name of Mobile River, runs 40 miles into the Gulf of Mexico. Next we have the Savannah, and, afterwards, the Roanoke, the latter entering the Atlantic in Albemarle Sound, after a course of 300 miles, of which the last 75 are navigable. The James River rises in the Aleghanies, and runs, also, about 300 miles into Chesapeake Bay. The Potomac enters the same bay, after running 400 miles, also from the Alleghanies. The Susquehanna rises in the state of New York, and enters Chesapeake Bay after a course of 350 miles, receiving several affluents. The Delaware is a similar stream, from the Catskill Mountains. The Hudson is an important river, navigable for large ships for 150 miles from its mouth, and forming by its estuary the harbour of New York. The Connecticut River is the principal river of New England, and its course is estimated at 410 miles.

The St. Lawrence is a gigantic stream, traversing the whole system of the great lakes of North America, and estimated to drain 300,000 square miles of country, of which one-third consists of the lakes themselves. The direct length of its course approaches 1,000 miles, and its mouth is 100 miles wide. Including windings its length amounts to 2,000 miles. It receives several tributaries from the north. Near its mouth, in the large estuary formed below Quebec, a vast number of islands communicate an extraordinary appearance to this stream.

Such are the conditions of the lands enclosing the Atlantic Ocean in respect to natural drainage by rivers. Gigantic systems characterise some very important tracts, while, elsewhere, there are intervals of coast line, exceeding 1,000 miles in length, without any river of serious importance. Let us now briefly advert to the river systems in the Indian Ocean and Pacific.

The south and east coast of Africa is broken by few rivers of interest, with the exception of the Zambesi, which, however, although one of the most remarkable streams in the world for the extent of its internal communications, is scarcely accessible from the sea, and does not deliver a very large quantity of water. The Great Fish River, (about 230 miles direct course), is the only other stream that needs mention. The greater part of the drainage of the Zambesi does not reach the coast, and thus this river was little known, and not recognised as an important stream till described by Livingstone in 1856. Its delta is 300 miles in length, and its whole course much more than 1,000 miles. It drains a very large tract of Africa south of the equator. There are no important rivers of the Indian Ocean system north of the Zambesi in Africa, none in Madagascar, and none in Arabia.

The Tigris is a river of nearly 1,200 miles length of course, joining the Euphrates, which drains almost the whole of Asiatic Turkey and terminates in the Persian Gulf. The course of the Euphrates is 1,800 miles, receiving several tributaries besides the Tigris, and bringing into the Persian Gulf a large quantity of mud. The area drained is not less than 260,000 square miles. The Indus is a river of the first class, rising in Thibet, 18,000 feet above the sea, and running 1,800 miles into the Indian Ocean. It receives five considerable streams (whence the name Pun-jab) and is navigable for nearly 1,000 miles. Its course is rapid, and it carries down enormous quantities of detritus. It drains half a million of square miles of India. There are no important streams entering the Indian Ocean on the west coast of the peninsula, but the Kistna and Godavery both rise from points of considerable elevation in the Deccan, and run eastwards into the Bay of Bengal. The former runs 800 miles, the latter 900 miles, both receiving considerable tributaries. Together they drain 250,000 square miles of country.

The Ganges and Brahmapootra, two of the great rivers of the world, combine to pour their waters into the head of the Bay of Bengal, through a large delta of mud, formed by their mutual contributions. The Ganges flows from the west, through 1,500 miles of northern India, receiving numerous streams and bringing down a vast quantity of mud, especially at certain seasons. The fall is inconsiderable for the greater part of the course. The Bramahpootra consists of the junction of two principal streams, one rising in Thibet and flowing west, the other rising near the sources of the Indus and flowing east. The total length of course of the principal stream from the east (which is not the longest) is about 1,000 miles. At some seasons it discharges more water than the Ganges. The Ganges and Bramahpootra together drain about 580,000 square miles.

The Irawaddy is another river of gigantic proportions. It is believed to rise in Thibet, and after traversing the Birman Empire, and passing through vast forests of teak, it forms a large delta, through which numerous streams enter the ocean. The delta, alone, occupies 10,000 square miles. The direct course of the stream is 1,250 miles, and the total drainage area 440,000 square miles. The Menam is another important stream, traversing Cochin China. Its drainage area is estimated at half that of the Ganges.

We come, next, to the great rivers of China. In China proper, the two chief streams are the Yang-tze-kiang and Hoang-ho. The total course of the Yang-tze-kiang is 1,750 miles in a direct line, or 3,300 including windings. The tide ascends 450 miles, and it opens into the sea by an estuary 30 miles across. The river is formed by the junction of two principal branches coming from East Thibet, near the source of the Irawaddy. After the junction it has a very tortuous course, and receives numerous large tributaries. There are many low islands at the mouth, formed by the mud brought down by it. It drains all the central provinces of China; the total area being estimated at 727,000 square miles. The Hoang-ho, or Yellow river, also rises in Thibet, and enters the Yellow Sea a little to the north of the Yang-tze-kiang, after running about 1,325 miles, not including windings, which double its length. It has two chief tributaries. It brings down vast quantities of yellow mud; whence its name. Its drainage area is estimated at 720,000 square miles.

North of China comes in the Amoor, a gigantic river navigable for 2,200 miles by steamers, and formed by the junction of two principal rivers rising in the central part of Northern Asia. The total length of course, including windings, is 2,750 miles. It drains 780,000 square miles.

The large streams that enter the ocean on the west coast of America are few in number. In the north we have Fraser River, in British Columbia, which rises in the Rocky Mountains, near Mount Hooker, and flows for about 620 miles, first NW., then W., and finally S. into the Gulf of Georgia, between Vancouver's Island and the mainland. It receives several tributaries, and drains a considerable area. The Columbia, or Oregon River, has a course of 1,000 miles, receiving large affluents, and entering the Pacific in latitude 46° 5′ N. The Sacramento is a smaller stream, but with a large drainage area. The Colorado of Upper California runs about 700 miles into the upper part of the Gulf of California. There is no stream of importance coming down from the western slope of the Andes, all the lands between the Pacific and the water-shed being dry, and the rains falling almost exclusively on the eastern side.

Australia is remarkable for the extreme rarity and smallness of its rivers in proportion to the extent of the land. The only stream of importance is the Murray, with its tributaries, the Darling, Morumbidgee, and others. After a tortuous course, commencing at the west side of the great mountain chain that runs parallel to the east coast of Australia, and continuing for about 1,300 miles, it enters the ocean as a noble stream, in latitude 35° 20′ S., longitude 139° E. It drains the south-eastern portion of Australia.

Besides the great rivers emptying into the Atlantic and Pacific, there are others that pour their waters into the Arctic ocean. These are numerous, and of gigantic size, and drain a marked proportion of the land of the eastern hemisphere, north of the equator. Commencing with those most to the west, we find the Dwina, which enters the White Sea by several mouths, after traversing about 330 miles of Northern Russia, and draining 44,500 square miles. The Petchora rises in the Ural and enters the Arctic Ocean, after a course of 1,000 miles through European Russia, draining 65,000 square miles. In Asiatic Russia, there is the Obe, with its mighty tributary the Irtish, coming from the Altai mountains, and, after a course of 2,000 miles, entering a wide gulf or estuary of the Arctic sea, draining a million and a half of square miles of northern Asia. The Irtish has a course of 1,700 miles, nearly half of it through China, and receives large tributaries. It enters the Obe about 180 miles north of Tobolsk. The Yenisei drains a million of square miles of the country east of the drainage of the Obe, and its course is estimated at 2,300 miles. It is a broad and deep stream, receiving many tributaries, and the surplus waters of Lake

Baikal. It enters the Arctic Sea by an estuary 30 miles wide. The Lena is scarcely less important, though it drains a somewhat smaller area, (800,000 square miles.) It runs for about 2,400 miles, entering the Arctic Ocean by numerous mouths. Eight hundred miles from the sea, it is between five and six miles in width, and would be navigable, but that it flows for a great distance through frozen deserts. It is the last of the great streams running northwards through Asia. The Indighirka, which enters the sea to the east of the Lena, runs only for 750 miles, draining 115,000 square miles, and the Kolyma, although it terminates with a wide estuary, (longitude 161°. 30′ E.), has a course of about the same length, draining, however, 150,000 square miles. On the other continent, the Mackenzie River, of North America, discharges its waters into the Arctic Ocean, after running about 900 miles from the Great Slave Lake, and receiving large tributaries, but it can produce little effect, in comparison with the great river systems we have been considering. It is estimated to drain 600,000 square miles. The Saskatchevan and Churchill are streams draining into the Arctic Sea large portions of the thinly inhabited countries in Northern America.

There are some, and not inconsiderable rivers in the world that do not reach the sea, terminating in lakes that have no outlet. The Caspian Sea is the largest and most important of such lakes, and it receives the waters of the Volga, the Ural and the Kur. The Volga is a noble stream, having a longer course than any other European river. It rises in the Valdai Hills, 550 feet above the sea, and enters the Caspian, after running southwards for a thousand miles in a direct line, or 2,400 miles including windings. It drains more than half a million square miles. As the surface of the Caspian Sea is at a much lower level than the ocean the total fall of the Volga is 633 feet. It receives many considerable tributaries. The Ural is also a very large river, draining more than 100,000 square miles, and running 1,800 miles, including windings. It drains the country to the north and east of the Caspian. It rises on the east side of the Ural mountains. The Volga drains the country on the western side of the chain. The Kur (Cyrus) enters the Caspian on the south-west, after running through Georgia. along a course of 520 miles, draining nearly 100,000 square miles. Hence it appears that the Caspian, whose area is about 24,000 square miles receives three rivers of considerable importance, draining in all nearly 700,000 square miles, besides numerous smaller streams, but that, in spite of these contributions, the evaporation from its surface is such as to keep the level more than 80 feet below that of the general ocean, with which it must once have corresponded.

The Sea of Aral also receives a considerable drainage. The Oxus, one of the great rivers of Central Asia, commences in a lake at an elevation of 15,600 feet above the sea, and after running 1,600 miles (920 in a direct line), and receiving large affluents, enters the Sea of Aral on the south side by numerous mouths. It drains 260,000 square miles. On the east the Sir or Jaxartes, a large and important stream, enters the lake by two mouths, after running 1,350 miles (direct course 680 miles) through 320,000 square miles of country.

Such are the main facts connected with the great river systems of the earth. If represented in their results, and in a tabular form, they will appear as follows:—

	Number of river systems.	Drainage area in 1,000 square miles.	Totals in square miles.
ATLANTIC OCEAN (47).			
Eastern Shore (32).			
European coast . . .	17	657	
Inland seas	10	1,910	
African coast	5	1,000	
Western Shore (15).			
South American coast .	3	3,585	
Inland seas	4	2,000	
North American coast .	8	800	9,952,000
PACIFIC OCEAN (13).			
Indian Ocean	8	2,680	
North-Eastern Asia . .	3	2,227	
American coast . . .	3	650	5,557,000
ARCTIC OCEAN (8).			
Old world	7	3,675	
New world	3	1,600	5,275,000
INTERIOR OF ASIA (5).			1,280,000
		Total	22,064,000

From this it appears that much less than two-fifths of the land of the earth is included in the drainage areas assumed. A very large part of Africa, four-fifths of Australia, a large proportion of South America, and vast tracts in North America and Northern Asia, besides the great islands of the world, must be brought into account to make up this difference; but it is clear after all that only a small part of the earth's surface is in any proper sense drained by the great rivers.

It should not be forgotten that river systems include properly only those areas draining directly into some one stream in its progress through the land. There are on all coasts very long distances between the mouths of great rivers, and often there are numerous depressions and ravines, bringing down flood water in large quantity. There is from the nature of the case great irregularity in the mode in which such supplies reach the sea, and much will depend on the climate, and the mode in which the rain-fall is distributed. It is safe to reckon as a general rule that about one-third of the total rain-fall of every principal drainage area enters the sea by the main channel, but that in addition to this a large quantity, amounting in some cases to a sixth part of the whole, may reach the sea without entering the main stream.

CHAPTER IX.

LAKES AND WATERFALLS.

1.—LAKES.

As rivers are natural channels on the earth's surface, along which water that has fallen from the skies as rain, or rises from the earth in springs, makes its way from the higher grounds to the sea, so lakes are depressions or basins in which the running water, checked in its progress, is forced to accumulate until it overflows the edge of the basin, or till it finds an outlet of equal capacity with the entering stream. Should there be no such outlet it is clear that the water must continue to accumulate until the evaporation from the surface equals the quantity of in-coming water. It is necessary that the reader should recognise clearly the force of this definition. All lakes are thus formed, except those which were once in direct communication with the ocean, and formed part of it. These must also be receiving daily supplies of fresh water, or they would become evaporated. Unless it is borne in mind that lakes are parts of the water really circulating on the earth, and are always being added to or diminished, a false notion of their uses and of their influence in physical geography must result.

Attending to this definition, it will be seen that there may be lakes having very different appearances, though all are caused in the same way. Thus there are mountain lakes, generally expansions of the valleys or natural channels through which streams pass in the upper part of their course, and while they are running with some rapidity. Such are the Swiss, Italian, and English lakes, remarkable for their picturesque beauty, because in the neighbourhood of mountains and shut in by high cliffs or lofty walls of rock. They sparkle with pure fresh water, or are black with the peaty matter of the hollows over which the water has passed. There is no limit to the height at which such lakes may exist, but that of the mountains among which they occur. They are often small, and generally longer than they are wide. They are portions of valleys, and partake of the general character of the surrounding scenery. They are almost infinitely multiplied, for the name may be applied to any body of water whose rate of progress has been sensibly diminished in any part by this temporary expansion of the channel, and it is used almost without reference to magnitude. Very small mountain lakes are sometimes called "tarns."

Lakes must vary according to the relative rate of entry and discharge of the water, and the amount of evaporation from the surface. In some cases the evaporation will be little greater than it would have been from the river if it had not been checked. All that is necessary to form a lake is that the water should be prevented from flowing for a time by some irremovable obstacle, so that there is an accumulation of its volume in an enlarged bed. Lakes thus formed are generally permanent, and subject to very little alteration of height or area. Their history is a matter which we shall have to consider afterwards.

But when water has issued from the mountains, and is traversing a part of the country comparatively plain, when there are no apparent obstacles to overcome, and the stream occupies local depressions of the surface because it has little or no motive power, the lake becomes a pool or pond, the water becomes apparently stagnant, and although a considerable stream may enter at one extremity, and a large body of water issue from the other, the water in the lake itself will not be in motion. Evaporation then removes a certain quantity, and the magnitude of the pool must depend on the ratio between supply and evaporation. Generally, when the one is greatest the other is smallest, and thus such lakes are very irregular in size. Lake Torrens, in Australia, Lake Tchad, and other great lakes in Africa, are among the most striking illustrations. These pools sometimes disappear almost entirely, and at other times are of dimensions so large as almost to rank among the principal lakes of the world.

In a few instances there is good evidence of the former presence of the ocean at its usual level in places where we now have lakes, whose surface is below the sea level. In these cases we have examples of portions of the bed of the ocean, which, by some accident, have been separated from the rest of the ocean floor without having themselves been elevated. It is a process, the exact converse of the formation of an island by the cutting through of some isthmus, which formerly connected it with a continent. Both are instances of interrupted continuity. When such lakes are formed, evaporation will take place from their surface, and they would become dry were they not supplied by the water of streams bringing in the drainage of the surrounding land. After a time a balance is struck between these supplies and evaporation, and the lake is more or less salt, according to the excess of one or the other. If the rivers bring in more water than is evaporated, the water is brackish, and at a higher level than the sea. If they bring in less, the waters are at a lower level, salter, more bitter and heavier than sea water, and this will be in proportion to the difference. Sometimes deposits of salt will take place at the bottom when the level of the water is greatly lowered. Should there be no drainage into a lake thus formed, so that the whole of the water become evaporated, the solid contents of the water must be left behind to form deposits. Such deposits exist among rocks in many parts of the world, as at Cardona, in Spain, in the Carpathians and Alps, and in the middle of England. Such deposits are being formed in the Dead Sea and in the Caspian.

Running water, bringing with it large quantities of detritus and mud, deposits a large proportion of this foreign material where it comes in contact with still water, whether fresh or salt, and thus there is a tendency to choke up lakes of moderate size. Near the sea, however, at the mouths of great rivers, or even where the actual streams are inconsiderable, a barrier often grows up beyond the ordinary limits of land. This is especially common in long lines of flat coast. In such cases the barrier becomes in course of time a long strip of low land, open, perhaps, to the sea at one or two points, but enclosing a large tract of shallow water. Such is the long spit of land, called the Lido, that protects Venice from the sea, and forms the *Lagoon*. Lagoons are lakes often shallow, formed artificially near the sea, where the level of the fresh water within the barrier or reef is the same as that of the sea immediately outside, and where there is little current of the water, either entering or emerging.

Such are the varieties of lakes. They exist in various countries, and however comparatively small, are really very interesting portions of the great aqueous sheet that covers so large a part of our globe. The quantity of water-surface within the land is at present not large compared with the surface of the land, and therefore very small indeed compared with the oceanic area. But it may not always have been so, for although a limit is put to the accumulation of sheets of fresh water by the balance of rain-fall and evaporation, this limit is by no means reached in the condition of the earth's surface with which we are familiar. All the surfaces of fresh water now on the globe would probably not exceed half a million of square miles, or less than one hundredth part of the area of the land—not one three hundredth part of that of the sea.

And the fresh water lakes that are known and described are distributed in a very peculiar and irregular manner. A large part of the area is to be found in a group, few in number, occupying a comparatively small district in north America. A large part of the remainder must be sought for in Central Africa. Throughout the rest of the world, although the number of such lakes is certainly enormous, the total area of water would hardly exceed 100,000 square miles.

The salt lakes are few in number, and their total area must be less than 500,000 square miles.

There are, however, many interesting peculiarities about lakes that render them well worthy of careful study as physical phenomena. They belong to the history of the earth, and are instructive to the geologist, as well as in the highest degree picturesque. We now proceed to describe the principal lakes of the different countries of the world.

Our own islands contain examples which, if small in actual dimensions, are not for that reason unimportant. In the mountain tracts of Cumberland and Westmoreland, and in those of Wales and Scotland, are many small mountain lakes. In Ireland are some of this kind, and others of larger dimensions occur in the flat table lands. The Cumberland lakes are singularly picturesque. Windermere, the largest, occupies part of a valley. It is 14 miles in length and one mile broad. Ullswater is 9 miles long, and about the same breadth. Derwentwater is 4 miles long. The others are much smaller All are narrow. They occupy enlargements of valleys, having a stream entering and leaving them. The wide part of the valley in some cases seems to have been swept out by water, and then by some interruption or accumulation at the lower part has been converted into a lake. It is thought by some geologists that ice coming down as glaciers from the mountains adjacent during the glacial period, has scooped out the beds of these lakes. The Scotch lakes are of the same general nature, but most of them are estuaries, the sea entering at one end. The water, however, is fresh and perfectly sweet. The Irish lakes are generally not enclosed by hills, but there are exceptions to this, as the beautiful lakes of Killarney. The Welsh lakes are few in number, and not large. Most of them, indeed, are mountain pools or tarns rather than lakes. Bala, which is four miles in length, is the largest of them.

France is without fresh water lakes, and except those of Switzerland and the Tyrol there are few in the central plains of Europe, north of the great mountain chain. Many of the lakes of northern Europe (Sweden, Finland, and Russia,) are pools in flat plains. Two important groups of lakes, most picturesquely situated, occur in the elevated land close to the Alps on both sides, near the lower parts of the valleys. After receiving considerable streams, some of the principal rivers of Europe run out from them, and carry off the overplus of water derived from the melting of snow on the mountains, and not evaporated.

Of the Swiss lakes, one of the largest and most regular in form is the Lake of Geneva (45 miles long, one to 9½ miles wide, area 82 square miles, height above the sea 1,230 feet, extreme depth 984 feet). It is a noble sheet of water, shut in on the south by lofty mountains, but open towards the north to the great plain of Switzerland. It receives several streams, and is subject to sudden rises of the water, amounting to 4 or 5 feet. The Rhone enters it from the upper extremity, and issues from it at Geneva. Its waters are of an exquisite blue colour. The Lake of Lucerne (24 miles long, half a mile to 2 miles wide, 1,380 feet above the sea, depth 300 to 900 feet), is a very irregular piece of water, occupying three valleys, and is entirely shut in by very lofty mountains. It connects with the Sarnen-see (3 miles long) and Lungern

See (smaller, and now partly drained). The Reuss enters it, coming from the St. Gotthard pass. The Lake of Zurich (26 miles long, half a mile to 3 miles wide, 1,342 feet above the sea), is enclosed by much lower hills than the lakes of Geneva and Lucerne. The Lake of Wallenstadt (11 miles long, 2 miles wide, 500 feet deep, 1,385 feet above the sea), is shut in by lofty mountains and steep precipitous cliffs. Thun and Brienz are smaller, but most beautiful lakes, between the Lake of Lucerne and the Lake of Geneva.

The Lake of Constance (42 miles long, 9 miles wide, 964 feet deep, 1,250 feet above the sea), is one of the largest of the Swiss lakes, but is somewhat outlying towards the north. The Rhine enters and issues from it. The waters of this lake, like those of the Lake of Geneva, are subject to sudden alterations of level. Below the town of Constance the lake, which is there reduced to a stream, widens again into a smaller, but beautiful lake, the Unter-see. The Lake of Neuchatel (25 miles long, 7 miles wide, 475 feet deep, and 1,420 feet above the sea), lies on the western side of the great valley of Switzerland. It connects with the Lake of Bienne (10 miles long, one mile to 3 miles wide, 400 feet deep, 1,410 feet above the sea), by a shallow stream. These two lakes are on the western or Jura side of the valley of Switzerland, and removed from the high Alps.

On the south or Italian side of the Alps there are also several lakes, at levels much lower than those of Switzerland. The principal are the Lake of Como (40 miles long, one to 3 miles wide, 600 feet above the sea); the Lago Maggiore (54 miles long, 3 to 8 miles wide, 1,100 feet deep, 678 feet above the sea); the Lake Lugano, between Como and Maggiore, (20 miles long, one mile to 2 miles wide, 500 feet deep, 800 feet above the sea); and the Lago di Garda (32 miles long, 3 to 13 miles wide, 950 feet deep, 230 feet above the sea). There are many others of smaller size, but for the most part they communicate with, and form therefore a part of the drainage systems of the great lakes.

These magnificent lakes, abounding in objects of interest, are, like those of the mountain district of Switzerland, expansions of valleys in which the drainage of the valley has accumulated. The Adda issues from the Lake of Como, the Ticino from the Lago Maggiore. The Lake Lugano communicates with the Lago Maggiore by the Tresa. The

Mincio issues from the Lago di Garda. All these rivers cross the plains of Lombardy and enter the great streams that traverse these plains from west to east to flow into the Adriatic.

Comparing the lakes on the north and south sides of the Alps, it may be observed that the latter are both at a much lower level and much deeper than the former. They participate in that abrupt and precipitous character by which the southern wall of the Alps is distinguished from the northern slopes. They occupy, on the whole, narrower, less regular, more precipitous, and more distinct fissures, and they communicate by much shorter channels with the ocean. All this is important, as belonging to the great physical construction of the continent, and its elevation from the great depths at which the rocks have probably been modified. In the Pyrenees there are small lakes at an elevation of seven or eight thousand feet above the sea.

There are a few other lakes not unimportant from their size and geographical position, situated on the north side of the main Alpine chain. Some are in Upper Bavaria and the Tyrol, others further east. Among them may be mentioned the Wurm-see in Upper Bavaria (12 miles long, 4 miles wide), discharging its surplus waters into the Ammer, which traverses another lake, the Ammer-see, (10 miles long, 4 miles wide) There is, also, the Chiem-see (12 miles long, 9 miles wide), a mountain lake, 1,550 feet above the sea, and 480 feet deep. Still further to the east is the shallow Neusiedler-see, (23 miles long, 7 miles wide), and the Platten-see, (48 miles long, 3 to 10 miles wide, 40 feet deep), whose waters are slightly salt, although it receives a number of streams. It is said that there are many thousand sheets of water in Bohemia, Gallicia and Moravia. They are all small.

Besides the lakes belonging to the Alpine system, Italy contains a number of small pieces of water, many of them occupying the craters of ancient volcanoes. Lake Thrasymene, near Perugia, is 30 miles in circumference. Bolsena (10 miles long, 8 miles broad), Vico (2½ miles long), near Viterbo, Lake Albano, near Rome, and some others, are more remarkable for picturesque beauty than for magnitude.

Northern Europe is not without great lakes. These are chiefly to be found on the eastern side of the Scandinavian mountain chain, and include the Swedish lakes Wenern and

Wettern, and Lake Mälar, the countless sheets of water of Finmark, the Russian lakes of Ladoga and Onega, and a few others less important. It is estimated that the lakes of Sweden cover nearly 23,000 square miles, or more than one-eighth of the area of the country. In Finland the proportion of water to land is still larger.

Lake Wener, (115 miles long, 15 to 30 miles wide, 144 feet above the sea), is divided into two parts by projecting headlands. The western part (called Lake Dalbo) is included in the above statement of dimensions. It is fed by numerous streams, and a considerable stream issues from it into the Cattegat, falling by several rapids. Lake Weter, (80 miles long, 10 miles wide, 420 feet deep, 288 feet above the sea), also receives many streams and torrents, and has a short and interrupted course to the sea. Lake Hielmar, (40 miles long, 2 to 12 miles wide, 78 feet above the sea), communicates by a stream of some importance with Lake Mälar, (70 miles long). This latter lake is exceedingly irregular, and crowded with numerous islands, so that hardly a mile square of surface is clear. It is nearly on a level with the Baltic. By the aid of canals and locks, connecting these with other systems of lakes, many of them of large size, a complete water communication is made through a very extensive area in Sweden, whose level varies from that of the Baltic to that of Lake Barken, which is 327 feet above the Baltic.

Finland is called by its natives the region of lakes. Elevated from 400 to 600 feet above the sea is a central plateau, more than one-third of which is covered with water. In the south-eastern part is Lake Ladoga, (120 miles long, 70 miles wide, area 6,500 square miles, extreme depth 900 feet), which receives the waters of Lake Onega, (120 miles long, 40 miles wide, extreme depth 900 feet), and conducts them by the Neva to the Gulf of Finland. Lake Saima, (180 miles long, 20 to 25 miles wide, and full of islands), and Lake Ilmen, (length 30 miles, breadth 24 miles, 107 feet above the sea), also communicate with Lake Ladoga. Lake Enare, in the north of Lapland, covers 1,000 square miles, and discharges its waters into the Arctic Ocean. A multitude of small lakes communicate with the Lake of Pyhäjärvi.

All these northern lakes, except those which are mere swamps, would seem to partake of the general character of the Alpine lakes, and to be connected with natural fissures in hard rock. Some are deeper than the adjoining ocean, and all belong to one class of phenomena. They are still subject in some small degree to the action of ice, but there can be no doubt that large masses of ice, either glaciers or icebergs, have, at some former period, glided or been drifted over them.

Continuing eastwards on the north side of the great axis of elevation of the eastern hemisphere, we find, south of the Ural mountains, and between that chain and the main chain, of which the Caucasus is an outlying portion to the west, a vast depression, described by Sir Roderick Murchison as the Aralo-Caspian depression. Within this space are the Caspian Sea and the Sea of Aral, both covered with salt water, and the former much below the level of the ocean. They are due to a different agency from that concerned in the formation of the fresh water lakes, being caused by some geological changes already alluded to. These salt lakes, therefore, are a class apart.

Besides the salt lakes there are, in northern Asia, several important sheets of fresh water. Some of them receive but do not discharge rivers, and some belong to the class of mountain lakes. Of the latter by far the most interesting is the Lake of Baikal, which, indeed, is the largest of its class. It is enclosed within the mountain ranges which skirt the northern side of the high table land of Upper Asia. It lies in the latitude of England, (51° to 56° N.), and in 104° to 111° E. longitude. It is 400 miles in length and from 20 to 50 miles across. Its depth is considerable, exceeding in many parts 100 fathoms, but it has not been carefully surveyed. It is fed by numerous streams, one of which (the Lelinga) has a course of 700 miles, another, (Upper Angara), of 450 miles. There are said to be nearly two hundred smaller streams emptying into it. The main outlet (the Lower Angara) is comparatively small, though its course is extremely rapid. The level of the lake is nearly 1,800 feet above the sea. The country around is volcanic.

The lakes of western Asia are not of remarkable dimensions. Lake Tengiz or Balkash is without an outlet, (length 150 miles, breadth 75 miles). It is situated near the northern edge of the great central basin of Asia. The Tehany, in Siberia, is 65 miles long by 40 miles wide, but is little known. In Persia, Lake Urumiyah or Shahel, (40 miles long and

25 miles wide), and in Asiatic Turkey (Armenia) Lake Van, (length 67 miles, breadth 25 miles, 5,467 feet above the sea), occupy lofty basins surrounded by steep mountains. Both are salt, and neither has any visible outlet. The former is very shallow, the latter deep in some places. Lake Seistan or Koh-i-Kwajeh, though of great area, (70 miles long, 18 to 30 miles wide), is a shallow pool in the high table land of Iran.* The largest is about 200 miles in circuit. All of them are connected with the general drainage of the country, and occur in the expansions of the principal streams.

The south side of the great elevated tract which forms the backbone of the old world, exhibits a number of peninsulas and islands, rather than any continued expanse of land. Africa, Arabia, India, and the Malay peninsula, are connected with the continent. The islands of the Indian Archipelago, Madagascar, Australia, and New Zealand, are detached. In none of these, except Africa, are there lakes of large dimensions, and even the African lakes are of the nature of depressed basins in plains or hollows in table lands, resembling in this respect the great Aralo-Caspian basin, and the exceedingly smaller but similar basin of the Dead Sea in Asia.

These various depressed basins are distinct, in many respects, from mountain lakes, even when they are at a very high level, as some of those in Africa. They occupy a different geological position, and though they receive and may discharge their overflow into streams of importance, they possess sufficiently marked peculiarities. They are often of very large area, and may be either salt or fresh, according to local circumstances.

The Caspian Sea is the largest sheet of salt water on the globe, not communicating with the ocean. From north to south its length is 750 miles, but a curved line through its centre, to the north-eastern corner, is 900 miles long. It varies in breadth from 150 to 270 miles. Its depth in the centre varies from 120 feet to nearly 3,000 feet. Its surface is 84 feet below the level of the Black Sea, and is said to be lowering. Its waters, though salt, are much less so than those of the ocean, as several large rivers empty themselves into it. The Sea of Aral is 265 miles from north to south, and 125 miles from east to west, but there is a prolongation to the north-east 100 miles long and 20 miles wide. Its depth in the centre is 90 feet, but it deepens towards the western shore. Its level is 37½ feet above the Black Sea, or 117½ feet above the Caspian. Large rivers flow into it, and its waters are rather brackish than salt, but it has no apparent outlet.

---

* It is a remarkable fact, and one well worthy of remark in reference to the origin of lakes, that the great Himalayan range is entirely without great sheets of water collected in the upper valleys of the rivers proceeding from them. Large lakes are rare in tropical regions, except in Africa, where they are specially abundant, large, and characteristic.

There would seem little doubt that both the Caspian Sea and the sea of Aral have formerly been connected with the ocean, and perhaps with each other. Since they have been converted into lakes, the difference in the magnitude and rainfall in their respective drainage areas has been such, that while the Caspian has sunk far below the original level, the sea of Aral has risen nearly forty feet above it.

The Dead Sea is small, but it is part of a considerable depression, separated from the Red Sea by a narrow tract of land of no great elevation. Its mean length is 35 miles, and its breadth 10 to 12 miles. Its level is 1,312 feet below that of the Red Sea. It is intensely salt; and bitumen not unfrequently floats on it. It is enclosed in a deep valley, and though it receives the waters of the Jordan, has no outlet, The lake of Tiberias occupies a part of the same general depression.

The lakes of Africa are, in many respects, very remarkable. There is a group of three, Tanganyika, Victoria Nyanza, and Albert Nyanza, recently discovered by the Nile explorers, which must be noticed as among the most remarkable known. The lakes Nyassa and Shirwa, discovered by Dr. Livingstone, are next in importance. Lake Tchad has long been known, and is also connected, inan important sense, with the physical geography of the African continent.

Of these lakes, the Victoria Nyanza and Albert Nyanza, both fresh water, must be regarded as the head waters of the Nile. The former (discovered by Captain Speke) is 3,308 feet above the ocean, and reaches from about 2½° south of the Equator, to about 20 miles north. Its distance from north to south is, therefore, about 200 miles. It is, probably, 300 miles from east to west, but its limits, towards the east, are not well defined. It reaches eastwards from about 32½° E.

longitude. Southwards, it has not been traced far. It narrows and becomes converted into a river channel; the stream is said to flow northwards. Passing by a succession of rapids and falls towards the north-west it receives several small additions, till in latitude 2° 20' N., and longitude 31½° E., it enters the northern extremity of the Lake Albert Nyanza, recently visited and described by Mr. Baker.

The Albert Nyanza is believed to extend south of the second parallel of south latitude, and may perhaps be connected with Lake Tanganyika, discovered by Burton and Speke. It reaches nearly to 3° N. latitude. Its length is at least 350 miles, and its breadth, for a considerable distance, 100 miles. It is 2,720 feet above the sea. The mountains enclosing the Albert rise about 7,000 feet above the lake, and are, therefore, 10,000 feet above the sea. A main stream of the Nile runs northwards from the northern extremity of the lake, and from this point the White Nile has now been followed to the sea.

The Tanganyika is a large and important sheet of water, at a much lower level than the Albert, but believed to connect with it. In that case, the Albert may be the head water, not only of the Nile, running northwards, but of streams running southwards, and connecting with the Shire river and its lakes, described by Livingstone.

The Tanganyika commences in latitude 3° 20' S., and extends to about 8° S. Its length is, thus, more than 800 miles. It is narrower than the lakes already described; increasing gradually towards the south, where it is about 60 miles wide. Its depth is unknown.

Considerably to the south of Tanganyika (the intermediate country, for a distance of about 500 miles, not having yet been visited by modern travellers) is the Lake Nyassa of Livingstone. It is more than 200 miles in length, from north to south, and varies in breadth from 15 to 60 miles. The northern extremity, however, has not been reached, and it may be connected, by means of open channels and other sheets of water, with the equatorial lakes. Its level is lower than that of Tanganyika, which was described by Burton and Speke as being 1,850 feet above the sea.

Still further to the south, but smaller and less important, is the Shirwa. It resembles the other African lakes in its general character.

Lake Tchad is a large, but indeterminate pool, situated in tropical Africa, nearer to the western than the eastern side of the continent, in latitude 12° 30′ to 14° 30′ N. Its length in ordinary seasons is upwards of 200 miles, and its breadth 140 miles. It is estimated to be 850 feet above the sea. It receives a considerable drainage, but is extremely shallow, generally from 8 to 15 feet deep, but varying with seasons. It hardly appears to have any defined boundary, as its size is greatly influenced by circumstances. It contains many islands, and both its shores and islands are cultivated. This lake has been frequently visited by travellers, but the accounts received vary a good deal from each other. This is no doubt chiefly owing to the very different aspect the lake exhibits at different seasons.

The Australian lakes greatly resemble Lake Tchad. They are very large at certain seasons, but one large lake becomes converted into half a score mere ponds in the dry weather. Originally visited and described by Mr. Eyre in 1840, Lake Torrens, in South Australia, was followed for 400 miles. Its width was from 15 to 20 miles. It is very shallow. It has since been found broken up into a multitude of pools. Two hundred miles to the south of Lake Torrens is the Alexandrian Lake. It is an expansion of the Murray River, and is about 30 miles across.

North America contains the largest and most important group of lakes in the world. Commencing at the north-western extremity, near the Rocky Mountains, we find the Great Bear and Great Slave Lakes, the former having an area of 14,000 square miles (height above the sea 230 feet, and depth 400 feet), the latter in a similar position, and of about the same area (300 miles long, 50 miles wide), and both discharging by the Mackenzie River into the Arctic Ocean. The Athabasca (230 miles long, 20 to 40 miles wide,) is scarcely smaller, and belongs to the same system. Wollaston and Deer Lakes are also large sheets of water. Winnipeg (240 miles long, 55 miles wide,) and Winnipegoos, not far off (125 miles long, 25 miles wide), are examples of lakes in flat countries emptying into a great arm of the sea.

Much further to the south we come to the site of the five larges sheets of fresh water in the world. Lake Superior is the largest of these (length from east to west 335 miles, or on a curve 400 miles, greatest breadth 175 miles, greatest depth 1,200 feet, height above Atlantic 857 feet). It receives many rivers, and its surplus waters, after falling and tumbling rapidly over innumerable rocks, enter a great bay, almost separated by a chain of islands and a long peninsula from Lake Huron, (extreme length 240 miles, breadth 60 to 220 miles, extreme depth more than 1,800 feet, height above sea 584 feet). This lake is divided into two portions (northern and southern) by the Manitoulin Islands. It is almost equal in area to Lake Superior, and communicates by an open strait, and without rapids with Lake Michigan, of which it might be regarded as a part. Taken in connection with Lake Superior the two lakes form a curve nearly 700 miles in length, running round from west to south east. At its furthest extremity Lake Huron connects with Lake Erie by the much smaller lake, St. Clair. But midway along this long curved line comes in Lake Michigan from the south. This great sheet of water is 300 miles long and 75 miles in average width. Its mean depth is 900 feet, and height above the sea 587 feet.

Lake Erie comes next in order (length 265 miles, breadth 80 miles, depth 84 feet, height above the sea 565 feet). Owing to its comparatively small depth it is less navigable than the other lakes, and is subject to sudden movements of the waters, but its waters are pure and transparent. It passes towards the north-east into Lake Ontario, by the Niagara River, falling 333 feet between the two lakes. Ontario is 180 miles long, 65 miles wide, 500 feet deep, and its waters are only 234 feet above the tide level in the St. Lawrence. All these great lakes, having a total area of nearly 85,000 square miles of water, are temporary interruptions of the passage of the great system of drainage of north-western America, as it passes down various streams and across a wide expanse of table land towards the St. Lawrence, by which river their waters are ultimately discharged. It will be seen by the above description that the waters of Lake Superior fall 270 feet to those of Huron and Michigan, and that these fall about 30 feet to Erie. The chief part of the fall occurs between Erie and Ontario.

There are few other lakes of importance in North America. Lake Champlain is 105 miles long, but only from half a mile to 10 miles in width, and has many islands. In Florida is a chain of small lakes terminating in Lake Okechobee, a round sheet of water 30 miles diameter. Lake

Pontchartrain (45 miles long, 23 miles wide,) is a lagoon rather than a lake, situated near the delta of the Mississippi. On the east side of the Rocky Mountains is a long series of lakes. many of them of volcanic origin, some intensely salt, and others formed of hot mud. Some are of dimensions which, in any other position, would demand attention; but they have been only partially described, and cannot for a long period possess any great economic importance.

In Central America there are a few lakes. Nicaragua is 140 miles long and 40 miles wide. Its surface is 128 feet above the sea. It connects with another smaller lake to the north, and both are separated by a narrow neck of land from the Pacific. Lake Nicaragua connects by the River San Juan with the Gulf of Mexico.

South America possesses few lakes of importance. The most interesting is Lake Titicaca, the most elevated large sheet of water in the world. Its area is nearly 3,000 square miles, its depth 720 feet, and its height above the sea 12,846 feet. It discharges its surplus waters to the south. There are several islands in it, and it occupies a depression in one of those singular valleys in the Andes of considerable breadth where two chains unite. In Brazil there are several lakes, the largest is Patos, an enlargement of the Rio Grande, (length 140 miles, breadth 40 miles).

From these statements the intelligent reader will not fail to gather the important conclusion, that while in various parts of the world there are important sheets of water, they generally occur in groups and systems, and that there are very extensive areas in which no lakes appear. It is also evident that the lakes are of at least two very distinct kinds, for while in many cases they occupy natural mountain valleys, accidentally closed at the lower end, in other cases they are open depressions on flat lands. Their picturesque effect depends greatly on the circumstances under which they occur.

2.—Waterfalls.

Rivers, both in their ordinary course, or when conveying the accumulated waters of lakes to a lower level, are subject occasionally to fall down rapid declivities, or leap over precipices. The rapids or waterfalls thus produced are sometimes phenomena of the most extraordinary and grandest kind, and require some special notice. It is by no means every great river that is subject to accidents of this kind, nor do all lakes in delivering their surplus waters from a higher to a lower level, meet with obstructions that affect the general features of a country.

The river Rhine, after leaving the lake of Constance, runs rapidly, and occasionally falls over a very irregular and rugged bed of rock, making a total descent of about 100 feet in the course of a very short distance, near the town of Schaffhausen. The great falls are about two miles below the town. The leap varies from 50 to 60 feet, according to the state of the river, and is divided into two parts by a detached mass of rock. The mass of the water is much greater than in any other European fall, but the height does not seem considerable when we compare it with the great falls in other countries.

Except the comparatively small but marvellously beautiful falls of the Alps, and several also of great beauty, though inconsiderable magnitude, in Norway, there are no other considerable waterfalls in Europe. The Handek is probably the finest in the Alps. The river Aar, after flowing rapidly through a narrow channel, for some distance, springs over a rocky ledge, and descends 200 feet into a dark chasm, whence clouds of spray ceaselessly rise. The Staubbach is very familiar to Swiss tourists, and remarkable for the extreme height of the unbroken fall, which amounts to nearly 900 feet. Seen in the morning, or by moonlight, it is hardly possible to imagine anything more beautiful than the effect, owing to the entire breaking up of the water by the air through which it passes. The quantity of water is seldom great.

There are several fine falls in Norway. The Sarp-fos, not far from Christiania to the south, is the name of the fall by which the river Glommen makes its way to a lower level. The river, measuring about 120 feet in breadth by 27 to 30 feet in depth, falls, vertically and unbroken, nearly 75 feet. There are some large masses of granite below the falls, over and among which the foaming water rushes a short distance, but then flows gently to the sea. The Riukan-fos, south-west of Christiania, is a fall of 900 feet, and the body of water is large, though inferior to that of the Sarp-fos. The Vöring-fos, on the Hardanger fjord, is also a very grand fall; the stream falling perpendicularly, without a single contact with the rock, for nearly one thousand feet, into a valley scarcely broader than itself. The volume of water is said to be about equal to that of the Handek, in Switzerland. In winter, the fall takes place within a case of ice. The Ostud-fos, also into the Hardanger fjord, is as much as 700 feet, and the body of the water is very large. The number of falls of smaller magnitude is exceedingly large.

Except the Rhine, none of the chief rivers, either of Europe or Asia, fall over precipices, and few of them, confined within narrow, rocky channels, inclined at a considerable angle, are interrupted in their navigation by serious rapids. Such rapids once existed in the Danube, where the river breaks through the western part of the Carpathian chain, but they are now rendered unimportant. The Rhine rapids have also disappeared. There are, of course, numerous mountain streams falling over the rocky ledges of the Himalayan and other Asiatic mountains, but they are not sufficiently remarkable to detain us here.

Africa exhibits two examples of large rivers tumbling headlong over precipices. The Zambesi possesses cataracts fully worthy of the name. They occur in the very centre of southern Africa, where the main stream of the Zambesi (called Leeambye) coming from the north and meeting an important feeder from the south connected with Lake Ngami, turns eastwards towards the Indian Ocean. Clouds of vapour from the falls, resembling smoke, are seen at a distance of six miles. The stream, half a mile wide, very deep, and running over a sheet of hard basaltic rock, towards the south, suddenly arrives at a broad, deep fissure in the rock, and plunges down at one leap at least 100 feet into a valley only about 50 feet wide. The upper part of the fissure is only 100 feet wide. The vast body of water thus disappearing, as it were, into the earth is carried away to the east in the direction of the open part of the fissure. The broken water rises in vapour 200 or 300 feet above the top of the falls. Dr. Livingstone states that he saw the falls at low water. At high water the vapour is said to be visible ten miles off, and the sound is heard at an equal distance.

Among the African falls the Ripon Falls, described by Speke, and the Karuma and Murchison Falls, visited by Baker, are also remarkable. By these falls the Victoria Nile or Somerset River, connecting the Victoria Nyanza with the Albert Nyanza, makes its way from the higher to the lower level, the difference of level being nearly 600 feet. The principal falls of the Nile are the Murchison Falls, where the river, 500 yards broad and of considerable depth, gradually narrows, and at length, confined in a narrow gorge scarcely 50 yards wide, leaps down precipitously for 120 feet into a dark abyss below. "The fall of water was snow white, which had a superb effect, as it contrasted with the dark cliffs that walled the river, while the graceful palms of the tropics and wild plantations perfected the beauty of the view."*

America possesses, in the great Falls of Niagara, one of the most remarkable cataracts in the world, and one which is far better known than others, owing to its position in a civilised and perfectly accessible country. The Falls of Niagara resemble, so far, those of the Zambesi, that they consist of a clean, unbroken fall of a whole river over a vertical precipice. The body of water is enormous, and the height very great. Having been accurately measured, and every detail recorded, these falls serve as a useful standard of comparison. The Niagara River is the name given to the channel conducting the waters of Lake Erie to Lake Ontario, and the difference of the level of the waters of these two lakes being 331 feet, and the distance or length of channel 33½ miles measured along its course, there is a fall of about 10 feet per mile. The breadth of the channel varies from half a mile to more than a mile, as it runs over a nearly level terrace of hard rock on issuing from Lake Erie. In this way, passing some islands and descending gradually, it runs for 16½ miles towards the north to Grand Island. At this point the river is about a mile wide and turns towards the west, running for 3½ miles over rapids, falling in that distance 66 feet, the last 51 feet being in the last half mile, terminating at the actual cataract. Up to the chief rapids the river is navigable. The Great

---

* Baker's "Albert Nyanza." Vol. ii., p. 143.

Falls are formed at a point where the river turns suddenly to the NNE. The banks are level and little above the water, in this respect agreeing with the Zambesi Falls. There is a very deep cleft or ravine in the direction of the water channel towards Lake Ontario, doubtless formed gradually by the undermining action of the water itself in the course of time. There are two falls, divided by Goat Island. That on the southern (American) side is 375 yards wide, the water falling 162 feet. On the other (Canada) side is the Horseshoe Fall, (so called from its shape), 700 yards wide and 149 feet down. The interval or breadth of Goat Island is 330 yards. The whole breadth of falling water is 1,405 yards, and the average quantity of water falling is estimated at 700,000 tons weight per minute. Below is a strong eddy or whirlpool. After running or about four miles through narrow precipitous rocks the river emerges, and runs again quietly for the rest of its course. It is impossible by any language or description to do justice to the extraordinary grandeur and impressiveness of the scene. It is one of those that must be visited to be understood.

Some of the rivers in the north-western part of North America are also remarkable for their cataracts, but they are little known and less visited. The Falls of Kakabika, where a torrent of water broken into foam leaps precipitously over lofty cliffs of sandstone, are, perhaps, the most remarkable.

CHAPTER X.

THE PHENOMENA OF ICE.

WATER in the gaseous state, or vapour, is so readily disseminated through and so easily held in air, and is so important and even essential a part of the earth's atmosphere, that it occupies in this, as well as in the liquid state, an important and definite place on the earth. The properties of ice or solid water, however, differ as essentially and completely from those of the liquid as these do from vapour, and in physical geography it is necessary to consider each separately. At present let us consider what is done by and with ice, and in what way it performs its task on the earth. In another chapter we will endeavour to trace the history of aqueous vapour in the atmosphere.

Snow is a form assumed by solid water in the higher parts of the atmosphere. It is one of the most beautiful and most curious objects in nature, and above a certain altitude, even within the tropics, it is formed in the air by the condensation of vapour, and may remain permanent in considerable quantity. When perfectly formed in very still air, snow is not a mere irregular aggregate of ice particles. In an ordinarily calm atmosphere water crystallises in hexagonal stars. From a central nucleus six spiculæ of ice radiate with perfect regularity, and between each two spiculæ there is an angle of 60°. From each of these six other spiculæ of smaller size are thrown off, always at the same angle, and so again others proceed from these in the same way. They are like the petals of a blossom, but exhibit the most marvellous variety, although all formed by a repetition of the same details. When there is much wind the snow forms in small pellets about the size of a pin's head. These are hard and frozen, and driven rapidly and far by the wind. Even in the warmest parts of the world, and where there are no mountains, snow is thus formed in the air at great elevations, owing to the rapid radiation that takes place when aqueous vapour is carried into the lighter and expanded parts of the atmosphere.

Thus there is everywhere a limit above which water only exists in the solid form, and the position of the snow line, as this limit is called when it touches the earth, is well known in all mountain districts. In the Andes of Peru it rises to 18,000 feet. In western Africa, at Kilmanjoro, it is estimated at 17,000 feet, but may be higher. Its position is by no means determined by latitude only, for in the Himalayan mountains the snow line rises to 19,000 feet on the north side, and only to 15,500 feet on the south side. So, also, in the Andes the height of the snow line under the equator is 15,795 feet, but in Peru it is at least 2,000 feet higher. On a general average, however, it may be stated at about 16,000 feet in the tropics, and whenever it is higher there is some local and exceptional cause for the phenomenon. From this altitude, as we advance northwards and southwards, there is a gradual but irregular descent. At Copiapo, in the Andes, it is 13,800 feet, near Valparaiso 12,780 feet, at the southern end of the Chilian Andes 8,300 feet, and in the Straits of Magellan only 3,390 feet. So in the northern hemisphere and on the great continent the descent is similar. In the Atlas mountains it is probably above 13,000 feet. In Sicily above 10,000 feet. In the Savoy Alps the limit is 8,500 feet. In Norway, however, it is less than 4,000 feet, and close to the Arctic Ocean it is 2,000 feet.

In the southern hemisphere there is no snow, even on the low lands, at the level of the sea, nearer the equator than the 48th parallel of latitude; but in the northern hemisphere this is by no means the case, and snow is occasionally seen in very much lower latitudes. This is the result of the mass of land and its influence on climate. In the western part of the old world snow falls near the sea in latitude 30° N., and on the eastern side of America the same limit is reached. In China, on the eastern coast of the old world, snow falls at Canton, but on the western side of America there is none below 48°. There are certain sheltered spots in Europe, some beneath the Alps, on the Gulf of Genoa, others on the south coast of

Spain, where snow is rarely, perhaps never, seen. These, however, are quite exceptional.

The number of days in which snow falls during the year varies, as might be supposed, according to the climate. Thus, at Rome the average is one day and a half, and at Petersburg one hundred and seventy-one days. The increment is very irregular. In England, and generally on the western shores of Europe, there is very little snow compared with places in the same latitude in the interior of the continent. Very large quantities fall on the east coast of North America in latitudes much lower than those of places in Europe where frost is little known. The conditions of a country under snow are, however, not such as to injure vegetation, for it is a bad conductor of heat, and extreme cold is never felt beneath the coating that accumulates during any single winter. Snow, as it usually falls, is not compact, and under ordinary circumstances it alters little when once on the ground.

Hail consists generally of a nucleus of snow, probably formed in the higher regions of the atmosphere, and coated with ice frozen upon it as it descends towards the earth. Hail almost always falls during storms, and is connected with considerable changes in the state of the atmosphere. Hailstones as they fall often become frozen together, so that occasionally large angular lumps of ice reach the earth, doing great damage to crops, and destroying much valuable property. The paths of great hail-storms are often very distinctly marked, and a storm is generally found to be extremely narrow in proportion to its length. A very destructive storm is recorded to have laid waste a narrow belt of country, extending between the south of France and Holland, traversing this distance in a few hours. On either side of the line thus drawn the mischief was extremely small.

Hail is most common in countries not far from mountains, but not necessarily adjoining very high land. It falls most usually during summer, and at or near the hottest part of the day. It is very rare on low lands within the tropics, but common at a height of a couple of thousand feet.

Ice is a substance familiar enough to the inhabitants of temperate and cold climates, and one whose properties are more or less known to every one, but the result of ice action on the globe is not so generally appreciated as the subject deserves. It well deserves a special and careful description.

Among the remarkable peculiarities of ice is, that it expands in the act of being formed, occupying more space than fluid water. This is, no doubt, the result of a peculiar arrangement of the atoms in crystallising, for no sooner do the polar forces begin to act, and solidification commences, than the atoms, in placing themselves in their new position, leave larger spaces between them than before existed. Whatever be the cause of this curious fact (which has been noticed also in bismuth and a few other substances), one result must be, that pressure, instead of tending to solidify, actually tends to prevent solidification, and thus the freezing point of solid water is lowered by pressure. It is possible to liquefy ice, in planes perpendicular to pressure, without in any way affecting its temperature. Ice does not so readily form at great depths of water below the freezing point, as in the same water near the surface.

Ice is always crystalline, and is therefore pure; taking up but little, if any, of the various substances contained in the water from which it was formed. The ice of salt water contains no salt and no air, with the exception of such bubbles as are caught up during the act of crystallisation. It has already been pointed out, that owing to its property of expanding during consolidation, ice is lighter than water not yet frozen, and thus floats on the surface, instead of sinking to the bottom. Being itself a very bad conductor of heat, a coat of ice, once formed, tends to keep unfrozen the remainder of a body of water exposed to intense cold.

Salt water requires a much lower temperature than fresh water to become solid, so that the sea is not frozen except in the Arctic Ocean, and then only during part of the year. The ice formed in this way (called pack-ice) is comparatively an unimportant part of that which produces, or has produced, a great mechanical result on the earth. The greater portion of this latter ice is derived from snow, and is the result of snow falling on land, where part of the land is above the height at which snow remains solid. It is thus limited to high latitudes, and it is clear that this fact excludes the possibility of any important ice effects being produced on low lands in the tropics and temperate zones It is, indeed, possible that the land on the earth might be so arranged that no perpetual snow should exist out of the circumpolar regions. One can even conceive, without difficulty, the conditions that should render large accumulations of ice altogether impossible on the earth's surface. On the other hand, by a certain disposition of the land, and especially of mountain chains, it might be possible to ensure perpetual snow from the tropics to the poles.

But the snow that falls in any one spot, even on the highest mountain, is not really perpetual. During winter, in certain situations, snow falls very frequently, and in large quantity. During summer, enormous quantities of it are always evaporated or melted. But this action is not everywhere reciprocal. Below a certain line, all that falls is melted. Above that line, the melting is not equal to the fall, and at the end of the year a residue exists. It must be manifest, that the line is subject to change in different seasons, but only within certain limits. Above this line, there must be a constant tendency to accumulate snow, and if, for example, a layer of three feet is added each year to the mass, this, in the course of a few thousand years, would completely bury the mountain, and rise far above its summit. No such accumulation takes place; but to prevent it, there must be some means beyond evaporation and the melting due to the summer heat. Among these means are avalanches, or falls of snow rushing down steep slopes into the valleys below, and melting when carried below the snow line. But there is still another, and a far more quiet, regular, and efficacious mode of relieving the mountains from their load of solid water. As one layer rests on another, the deeper portions of the snow become squeezed and consolidated,—the air is pressed out, and the already frozen particles in contact with each other, aggregate, and become ice. The mode in which, by a little rolling and squeezing, a snow ball is first made, and then enlarged, is familiar to every school-boy. The pressure being increased, the snowball becomes solid, though still admitting of a certain yielding to further pressure. So soon, then, as a large quantity of snow has collected in some recess, such as a valley above the snow line, the lower portions are squeezed, and carried down the valley, creeping on slowly but inevitably, and combining a motion of the snow among its own particles with a general travelling down of the whole mass. If the general bed slopes downwards, but is uneven and irregular, the whole mass will move over the irregularities, rising over and tending to grind, scar, furrow, and carry away whatever comes in its way, and often polishing the hardest stones by the combined action of the frozen snow, and the sand, stones, and rocks that gradually become buried in it. Generally, the tongue of ice that descends below the snow line, melts away before it has advanced very far, and thus the balance is kept up. Not unfrequently, however, in certain mountain districts, large and deep valleys receive the masses thus sent down; in these valleys they become yet more consolidated; several streams of ice meet together, and the whole moves onwards, for a great distance, at a slow but measurable pace, imitating closely the motions of a river, and conveying the combined mass far away from the mountain valley in which the snow fell to which they were due. Here, also, the ice is carried forwards until the consumption and waste below equal the supply from above, and at this point a stream of water commences. It may be only a few hundred yards, or it may be twenty miles below the summer snow line, that we have permanent ice. Above the snow line, both in summer and winter, there is always snow on the surface and ice below. The portion below the snow line becomes a *glacier*, and the part above the snow line is called *névé*, (in German, *Firn*). The névé is the feeder of the glacier.

Névé is formed, and the structure of glacier ice obtained by the following process. The snow having fallen, and become drifted, the action of the sun on the mass of snow dust and crystals partially melts them, and causes them to form into larger grains, which become further compacted and frozen together during the next interval of cold. When the interval is long between two falls of fresh snow, this change is continued far down into the first fall; and, on the other hand, the sooner a fresh layer falls, and covers up the former, the more imperfect will be the conversion, and the less compact the *névé*. In the course of years, however, the *névé* increases, by successive strata, until the whole mass, pressed downwards by a considerable weight, is thoroughly compacted, and converted into glacier ice. It also becomes cracked and fissured, often to a great depth.

The essential condition for a glacier is the existence of some ravine or valley, at sufficient height on a mountain side, and at such a slope, as to allow of the accumulation of *névé* to such an extent, that its weight can force down the whole mass into the valleys below, where the ice brought will be melted. The whole moves together, but neither in the way of a solid or fluid. It moves more or less slowly, according to the conditions to which it is exposed. The central part moves most rapidly: the whole moves faster in summer than in winter. But the motion is slow. A few inches per day is not unusual, and it is rare that the most rapid progress exceeds two or three feet. The cold of winter penetrates but a short depth below the surface, and thus the motion continues all the year round, though accelerated in summer.

Occasionally, there are glaciers of which the *névé* is imperfectly formed. They reach steep slopes, and yet move but little. They rather slide like solids, than move with the plasticity of characteristic glaciers.

Glaciers are rent through by deep and numerous fissures,—most numerous and widest in summer, but constantly closing up and re-formed. Streams of melted ice, running along the surface during summer, are received into these crevices and escape. An enormous loss of the upper part of the glacier takes place every year, and the lower parts, with their contents, are constantly brought to the surface. As a vast quantity of fragments of rock are received on the ice, these are at length laid bare: and thus are produced those streams of stones and gravel known as *moraînes.*

Of such a nature are the masses of ice that are accumulated in many of the higher valleys of the Alps and of other mountain chains. When, however, a glacier runs down so far as to reach and enter the sea without melting, although it may continue to advance through the water, its mass, which is lighter than the corresponding bulk of sea water, must at last break away, rise to the surface, and float off. In this state it is an *iceberg.*

It is very important that the student should be familiar with the phenomena of ice in order to understand the effect of glaciers and icebergs on the earth's surface. If we follow the course of one of the great glaciers of the Alps, we shall find that several tributaries help to form one great glacier. Both the smaller and principal valleys are often tortuous, and the tributaries not only change their direction, but mingle their currents to form the ultimate mass. The glacier must often force its way through narrow gorges, and sometimes may be pushed over large open spaces, and even over rising ground. Everywhere it must overcome or overpass the natural obstacles that lie on the surface in mountain countries. The total motion of the most rapid part may not exceed an inch an hour—

it may not be more than a few inches per day; but the motion follows the same laws as that of a river, the line of greatest rapidity changing from one side to the other, as the form of the valley requires,—the whole mass sometimes accumulating or seeming to accumulate in tranquil places, but the central part always moving on and dragging the sides with it.

In popular language, it has often been said that the motion of the glacier as it descends is like that of a tenacious fluid. But, strictly speaking, this language is incorrect; for all viscous fluids move like treacle or tar, and in adapting themselves to irregularities of surface they act precisely as other fluids. Ice is, however, a solid, and is not capable of this. In the place of it there is a peculiar physical property possessed by solid water to which this accommodating faculty is owing. It arises from the property of *regelation*,—a property familiar enough and easily illustrated by experiment, and one of very considerable importance in nature. It is illustrated by the fact, that if two flat surfaces of ice are brought in contact, the two surfaces at once freeze together and become solid. Faraday has shown, that if a number of pieces of ice are floated in a basin, then, if one piece touches another, if only at a single point, they become attached; and thus a train of such pieces may be formed, one dragging all the rest. If in such an experiment a bend is made, the chain is broken, but as quickly re-cemented. "Thus, a wheel of ice might be caused to roll on an ice surface, the contacts being incessantly ruptured with a crackling noise, and others as quickly established by regelation."* It is well known, that the mere squeezing of snow granules by the foot produces rigidity and makes a solid bridge, for without this property it would often be impossible for the mountaineer to advance, when ascending lofty snow-covered mountains or crossing fissures in glaciers. It is easy to produce any form in solid compact ice by squeezing it into moulds —a result entirely due to this process of regelation.

When, then, a mass of snow is compressed vertically and pushed laterally by its own weight as it descends some ravine, it is not difficult to understand that this power of regelation or freezing into some new form immediately after being broken, does in fact simulate the behaviour of a viscous fluid. But, however capable of adapting itself to the exact form of the ravine or valley through which it is forced by its own weight to pass, it is still, at every instant of its existence as a glacier, a solid body, behaving in every respect as a solid on the rocks between or over which it passes. Loaded with rocks and stones brought down by the action of the weather from the higher parts of the mountains, it exerts, partly by the aid of these and partly by its own weight and friction, an enormous mechanical power over the rocks in its progress. This may be recognised along the path of a glacier that is now threading its way down a valley. But it is yet more clearly seen in reference to ancient and much larger glaciers, that once coursed down these valleys and entered the plains below. "Go, for example, to the glacier of the Aar, in the Bernese Alps, and observe its present performances; look to the rocks upon its flanks as they are at this moment rounded, polished, and scarred by the moving ice. And having by patient and varied exercise educated your eye and judgment in these matters, walk down the glacier towards its end, keeping always in view the evidences of the glacier's action. After quitting the ice, continue your walk down the valley towards the Grimsel; you see everywhere the same unmistakeable record. The rocks which rise from the bed of the valley are rounded like hogs' backs; these are the *roches moutonnés* of Charpentier and Agassiz; you observe upon them the larger flutings of the ice, and also the smaller scars scratched by pebbles, which the glacier held as emery on its under surface. All the rocks of the Grimsel have been thus planed down. Walk down the valley of Hasli and examine the mountain sides right and left; without the key, which I now suppose you to possess, you would be in a land of enigmas; but with this key all is plain: you see everywhere the well-known scars, and flutings, and furrowings. In the bottom of the valley you have the rocks filed down in some places to dome-shaped masses, and in others polished so smooth that to pass over them, even when the inclination is moderate, steps must be hewn. All the way down to Meyringen, and beyond it, if you wish to pursue the enquiry, these evidences abound. For a preliminary lesson in the recognition of the traces of ancient glaciers, no better ground can be chosen than this.

---

* "Tyndall's Heat," p. 186.

"Similar evidences are found in the valley of the Rhone; you may track them through the valley for 80 miles, and lose them at length in the lake of Geneva. But on the flanks of the Jura, at the opposite side of the Canton de Vaud, the evidences re-appear. All along these limestone slopes you have strewn the granite boulders of Mont Blanc. Right and left, also, from the great Rhone valley, the lateral valleys show that they were once held by ice. On the Italian side of the Alps the remains are, if possible, more stupendous than on the northern side. Grand as are the present glaciers to those who explore them in all their lengths, they are mere pigmies in comparison with their predecessors."*

Although the Alps, as being the nearest and most accessible mountains to European travellers, have been more studied than any others in reference to their glaciers, they are not alone in this respect, neither are they remarkable for the comparative magnitude and importance of the phenomena indicated.† Most of the great mountain chains exhibit glacial phenomena to a greater or less extent, though in some, as in the higher Andes, the position of the mountain chain with respect to the prevalent winds renders them comparatively unimportant. In the island of New Zealand, where there are lofty mountain chains, the glaciers are on a grand scale, and the moraines derived from them are described by Dr. Haast as being unusually well defined and plentiful. The Tasman glacier is 12 miles long, and at its lower extremity 1¾ miles wide.‡ In the Himalayan mountains the glaciers are far more remarkable. The tributaries to some of those of greatest magnitude are from eight to ten miles long; and the great glacier of Mustakh, described by Capt. Godwen-Austen, was 36 miles in length in a part which was actually surveyed trigonometrically. These glaciers are not less remarkable for their enormous width than for their great length. The Arctic and Antarctic regions, again, afford other instances in which rivers of ice enter the sea after a long course over lands not so lofty, but where the snow-line is much lower. There are very fine glaciers in the Norway mountains, and those of Greenland are yet more remarkable.

It has long since been noticed that in many districts where now there is no perpetual ice, and where even snow itself is a rarity, there are marks on the surface of the ground precisely similar to those produced by glacier action. That glaciers are powerful agents, both in breaking up and carrying away rocks of various sizes and every degree of hardness, there is no doubt. That when the ice is melted the rocks and fragments are left behind, if too heavy to be transported by the current of running water that replaces the glacier, is equally certain. When, therefore, we find in the great valley of Switzerland, or on the sunny plains of Lombardy, indications of the presence of ice precisely identical with those met with on the sides, or close to the extremity of recent glaciers, it is impossible or at least unreasonable to resist the conclusion, that ice has once been present there also, and that there are extinct glaciers, as we know there are extinct volcanoes.

---

* "Tyndall's Lectures on Heat," p. 190.

† The largest Alpine glacier is that of Aletsch, descending from the south side of the Bernese Oberland. It descends in an unbroken stream for a distance of 15 miles, and an average breadth of one mile. The Rhine, Rhone, Po, and Adige, are all fed by Alpine glaciers.

‡ "Proc. of Roy. Geog. Soc.," Vol. viii. (1864), p. 57.

But it is not only near the mountains where glaciers may still be studied that we find proof of the former action of ice, where now no ice is seen. Similar appearances may be seen and studied in the hills of Cumberland, Wales, Scotland, and Ireland. Where there has been a long exposure to weather in a climate like ours the finer scratches on the rocks have disappeared, but the peculiarities of form produced by the grinding action of moving ice has been preserved. When in such cases the rocks are covered by vegetable soil, if we remove this soft covering we may often find even the striæ preserved, and the surface scarred as deeply, and polished as perfectly, as those polished and furrowed on the flanks of the Alpine mountains. In Cumberland, Scawfell and Borrowdale exhibit abundant indications of ancient ice in *roches moutonnés* and *blocs perchés*. And so, also, in North Wales, all round Snowdon, the same things may be observed, while in the south-west of Ireland, near Killarney, there is evidence that the ground now occupied by the lake was once covered by a glacier, every islet that exists being even still recognisable as a glacier dome. The whole of northern Europe and North America abound with proofs of the same action. Everywhere ice has been at work, for the most part proceeding from mountains near at hand covered with snow, when the snow line was much nearer the sea than it now is, and with snow converted into long tongues of ice stretching out in every direction, and producing the flat denuded surface so familiar and characteristic of those regions. Very far south the lands of Europe, and even of Asia Minor, at a time geologically almost recent, have been subject to the passage of ice across them, for it has been determined that even the celebrated cedars of Lebanon grow upon ancient glacier moraines.

But we have spoken of icebergs as well as glaciers. When in high latitudes a glacier enters the sea and is broken off, it floats away in very cold water, and being carried along by marine currents, may be carried for hundreds or even thousands of miles through the ocean. Icebergs vary in size from a few yards to many miles in circumference, and in height above the water from a few yards to several hundred feet. For every foot above water there are from 8 to 10 feet below the surface, and thus many of these masses may be stranded on submarine plateaux a thousand fathoms deep. Over these they must be occasionally dragged for some distance, owing to the enormous momentum of a mass of moving ice of millions of tons weight. Their burden of stones and sand must be left behind when the ice has melted.

Icebergs, in those parts of the Atlantic where they cross the path of ships proceeding to and from America, are common enough, but are not often seen to advantage, owing to the condensation of vapour and formation of constant mist around them. Their presence can very generally be told in the Atlantic by steady observation with the thermometer, and as they are extremely dangerous, the careful navigator watches for and evades them. It is only in the late spring months, when the ice is partly melted, that they descend in large numbers to low latitudes. In the southern hemisphere they cease ten degrees of latitude nearer the pole than in the northern.

Icebergs seen under favourable circumstances, and without mist, appear to have steep cliffs with a glittering surface of an emerald green tint, and pools of water often lie on their surface, or are projected in cascades into the sea. They are constantly changing in form, melting generally with great rapidity, both below and above the water line, so that their centre of gravity is perpetually shifting. Occasionally they topple and fall over, and if too near, are likely to be dangerous to ships, owing to the enormous displacement of the water that then takes place. It is, however, not very frequently that the state of the atmosphere is such as to allow icebergs to be seen at a distance, and no ship would approach them knowingly and willingly. It has happened in the Atlantic that large steamers have fallen in with groups of icebergs in which they have become entangled, and from which they have only escaped with great difficulty. Others whose history has never been known, have no doubt been destroyed by the too close contact of these monsters of the deep.

There is no doubt that ice must have covered a large part of the northern hemisphere during the late tertiary period. Abundant evidence of this is to be found on the rocks that have been ground, polished, and scratched, while the sheet of ice was being dragged or pushed over them. The whole of northern Europe, and probably of northern Asia and North America, to latitudes below those of the great chain of the lakes, have been included under this icy shroud. In earlier times there would seem also to have been periods of cold admitting of glaciers, although the evidence adduced is hardly sufficient at present to justify an absolute conclusion to that effect. This is partly owing to the long lapse of time and the enormous amount of denudation. It is, however, certain that gravels of certain kinds, including angular boulders such as are now characteristic of glaciers, are met with in rocks of ancient date. Smooth and striated surfaces of rock, apparently scratched by the passage of heavy masses over them, and some other phenomena of like nature, are also among the illustrations that have been brought forward in proof of the assumption of ancient glacial action. During the deposit of the Permian rocks, and while parts of the old red sandstone were being accumulated, glaciers may have overspread Europe.

Of late years there has been a tendency to assume the probability of one uniform coating of ice having formed a kind of ice-cap over all the northern lands of the earth, similar in some respects to what seems to be the case with the planet Mars. This is not the place to discuss a question so purely geological, but it is worth while to call the attention of the reader to it, as connected with the existing physical geography of a planet closely resembling our own in many respects, and one of our next neighbours among the bodies of our system.

CHAPTER XI.

SPRINGS.

Of the water that falls on the earth as rain, we have seen that a certain part runs off the surface by rivers into the sea, or is evaporated back again into the atmosphere within a very short time. The remaining part disappears. It passes into the earth's crust, being absorbed into the soil and surface-rocks, or entering the innumerable crevices and fissures that exist in all rocks near the surface. Making its way through permeable rocks, such as sand, or passing into natural reservoirs or along some underground channel, it circulates through the earth for a time, longer or shorter according to circumstances, and comes at length once more to the surface. If it falls in a district greatly above the sea level, it may issue in springs at some lower part of the same country, or, by the pressure it exerts when the rocks are full, may force out other water that has already performed a long journey. If it falls near the sea, it may still be brought back into circulation, for we know that the temperature of the interior of the earth is higher than at the surface; and it is quite possible that a little water, penetrating the depths at which it would be converted into steam, may exercise a pressure sufficient to overcome the force of gravity, and help to force up large columns of water from great depths, which may either rise through fissures at a high temperature in thermal springs, or, oozing upwards, may again become cooled before reaching the surface. It may and does re-appear in this way naturally, and at ordinary temperatures. All water obtained or obtainable from the interior of the earth is called *spring water;* and all sources of water within the earth are called *springs.* They differ in their nature very considerably; and we will first see in what they differ, and how the conditions are to be explained.

Of ordinary springs there are three kinds, if we regard the subject from a geological point of view. Thus, if the rock at the earth's surface, in any locality, be perfectly open and permeable, like gravel or sand, resting on some close rock, as clay, all rain falling on it sinks in at once to the impermeable floor and forms pools in the irregularities of that floor. When a hole is dug in such sand or gravel, water will rise in the hole to within a little of the general depth at which the sand is wet. This may be seen by experiment on a small scale on the sea shore. Such springs are called *land springs.* They are useful, but the water is liable to injury from impurities present at the surface; and during long drought land springs are almost sure to become dry. Water, however impure, and even when largely impregnated with salt, becomes drinkable, and freed from organic impurities, when it has percolated for some distance through almost any kind of permeable rock.

When a permeable bed, as of sand or loose gravel, lies between two impermeable beds, as of clay, the sand is sure to receive and absorb much water along the line of its outcrop. As almost all rock-beds or strata are inclined more or less to the horizon, the water descends and collects in these beds. If a water-bearing bed is reached by a well sunk through an upper impermeable covering, the water will rise to find its level; and in the case where the water enters at a higher level than that of the place where the well is sunk, it may rise up to or even above the surface. Springs obtained in this way are called *Artesian*, from the town of Artois, in France, where such sinkings as we have described attracted attention during the middle ages. The discovery, however, that water could be obtained by such sinkings, is at least as old as the civilization of Egypt; and Artesian wells, as they are now called, are very much more ancient than the name of Artois.

Many varieties of geological condition and position of the rocks modify the circumstances under which water can be obtained, or the mode in which it naturally flows in springs. Thus, where the rocks have been broken and fissures produced that are open to the surface, water will rise through such fissures as into a well. If, after fissures have been formed naturally in rocks, the whole mass has been upheaved, and the flow of water stopped by an impermeable rock coming against a permeable sand, it is clear that the water must tend to find its way out. It will pass downwards, if possible, but failing any downward exit, or if the rock below is already full, it will inevitably rise towards the surface through any open channel, and it will generally be able to rise, for the earth is rarely so close as not to admit of some outlet, and this is soon enlarged where water runs through and pressure is exerted. It is certain that water must be constantly circulating through natural fissures in the earth at all depths, and at those depths where the temperature is high the water will become warm.

In limestone districts, where the rock, though absorbent, is naturally much broken, and where the material is readily acted on and dissolved by water, there are usually caverns and open spaces. In these, also, water collects, and through or amongst them it passes, dissolving the limestone at one place and depositing it in others, according as the course of the water is rapid and the absence of air complete, or the course slow and evaporation considerable.

Water that rises from the interior of the earth, or that has passed through the earth is not chemically pure. In one sense, indeed, no water is pure; for even the rain, before it has reached the earth, has absorbed mineral matter from the atmosphere. But the water of springs not unfrequently contains gases, mineral salts, acids, bitumen, and even organic matter, in quantity sufficiently large to produce a marked influence on the animal economy. In this respect, however, there is great difference. Thus, the waters of Néris (near Montluçon, in the middle of France), whose temperature is 125° F., exhibit, on analysis, an extremely minute per-centage of saline matter, and a very little organic matter. The waters of Schlangenbad, near Wiesbaden, contain even less than this, though they have a high reputation for sanitary purposes. The Wildbad spring, near Stuttgard, contains only about twenty-three grains of solid matter per imperial gallon. On the other hand, there are waters that contain upwards of sixteen ounces of salts of various kinds in the gallon.

Mineral springs very frequently emerge in the neighbourhood of volcanoes, and there is no known volcanic region in which they are not found. They also occur near the points where granite and other metamorphic rock comes to the surface, and wherever lines of fault and fissure open a passage from considerable depths to the surface. The celebrated springs of

Carlsbad originate along a line of contact of two granites of different geological age. Other springs arise from the contact of slate with granite; and, generally, the contact of two dissimilar minerals or rocks, capable of exciting chemical action, is marked by phenomena of this kind.

It is not always within small areas or along lines of fault or dislocation only a few miles in length that mineral springs issue. Humboldt has indicated, in South America, a line of nearly five hundred miles along which such phenomena occur. A considerable district in central France contains mineral springs in vast number. In most of the principal mountain chains of the world, something of the same kind can be traced; and indeed there can be no doubt that some relation may generally be traced between the points at which mineral springs issue and well-marked geological phenomena, not only volcanic, but disruptive, independent of the vicinity of volcanoes. There are few countries, however, in which mineral or thermal springs have not been met with, and their recorded number is very large, though by no means including all that might fairly claim the title. As many as 864 have been described in France, and about 400 in Spain, while the number in Germany and Switzerland, though not est'mated with such precision, must be much larger.

The quantity of water issuing from springs varies, as might be supposed, to an almost indefinite extent. It is in many cases very difficult, if not impossible, to gauge them with accuracy. The waters at Carlsbad are estimated to yield at least a quarter of a million gallons per day; and several hot springs described by Humboldt, in South America, pass away almost at once through regular channels as large rivers. In Switzerland, the spring of St. Laurent, at Leuk, yields 280,000 gallons per day. In the Pyrenees, the springs of Cauterets yield nearly 90,000 gallons per diem, and those of Olotte nearly 400,000. On the banks of a small stream in the State of Arkansas, North America, as many as sixty springs appear in a distance of a quarter of a mile, with a temperature varying from 125° to 160° F., and a total volume of 300,000 gallons per day Cold springs rise immediately adjacent.

In central France, where thermal springs are very abundant, there is one (Bourbon l'Archambault) that yields half a million of gallons per day, and the combined yield of all the springs of the district, whose number is upwards of five hundred, is certainly not less than 3½ million gallons per day, and is probably much greater.

It is to be remembered that in all these cases the actual quantity of water lifted from the depths of the earth towards the surface, must very greatly exceed the quantity measured and running over the surface. A great deal of the water percolates the beds through which the column rises. This is especially the case where the springs rise at the contact of granites with stratified rocks of open texture, such as calcareous rocks and travertins into which water passes very readily. Numerous instances of the dissipation of strong springs are to be found at Vichy, Clermont, and in other places in the centre of France. Other instances are known of powerful springs not reaching the surface, and only known when tapped during mining operations. A remarkable case of this kind occurred in Cornwall some years ago.

The temperature of mineral springs varies from some degrees below the mean temperature of the place where they issue to many degrees above the boiling point of water. Very large springs are often warm, though by no means always among the hottest. The hottest known are directly connected with volcanoes, as in Iceland, but many whose temperature is upwards of 120° F. occur in positions altogether removed, not only from volcanic agency, but from any highly metamorphosed rocks.

Besides the boiling springs of Iceland that of Trincheras, near Puerto-Cabello in Venezuela, South America, affords one example, and those of Arigino, in Japan, another. The latter exceed 212° F., and rise in steam.

In the Pyrenees the highest temperature is about 140° F. In Central France the Chaudes aigues Springs attain a temperature of 180° F., but the others are much below. The great majority of thermal springs are below 100° F., but it is probable that this is due partly, if not entirely, to the nature and temperature of the rocks through which the water rises and the difficulties it has to encounter before reaching the surface. The mineral springs in England are sufficiently remarkable and numerous. Among them, those at Bath and Buxton are hot, the former rising with a temperature of 115° F., the latter of 82° F.

Mineral waters may be expected to contain all those substances which water in its passage through the earth can find and dissolve. The tendency of minute analysis is to show that water is a universal solvent, and although the presence of one group of minerals may prevent the water from taking up some others, we may still expect a great variety in those which have risen from great depths, or traversed long lines of strata. Water is a solvent at all known temperatures. Cold water is sometimes a more powerful solvent than hot, but, generally, with increased temperature, so far as it is attained in the interior of the earth, and according to the length of time during which it may have moved through mineral veins or other crevices, the number as well as the variety of the contents will increase. Still the number of substances generally found in mineral springs in important quantities is very limited. A small number of acids and an equally small number of bases reciprocally saturating one another completes the list. When the saturation is incomplete it is always the acid that is in excess.

The following are the acids most generally met with :—carbonic, sulphuric, hydro-chloric, hydro-bromic, hydriodic, nitric, phosphoric, boracic and arsenious. The following are the bases :—soda, potassa (rarely), lime, magnesia, lithia, the oxides of rubidium and cæsium, oxides of iron and manganese. Besides these, are oxygen, nitrogen, silica, alumina, and certain nitrogenised substances. The tendency of discovery is to increase this list, and also to increase the number of elements belonging to any particular spring, and the use of spectral analysis, introduced only within a very short period, has already done much to improve the state of chemical knowledge in this matter. One of the first results of spectral analysis was the discovery of a new metal, cæsium, in mineral waters. It may be supposed, and is the case, that of these elements the quantity present in the quantity of water experimented on is often so small that only a trace is indicated, but such traces become important in estimating the effects of the water either on mineral veins, strata, or the organised beings that come under its influence. Besides the mineral acids organic acids are occasionally detected. In the waters of the Sprudel Spring at Carlsbad, the water is said to contain about 463 grains per gallon of solid matter, and to include the following list of substances. Sulphate of potash (nearly 92 grains) arsenic, iodine, bromium, antimony, gold, copper, chromium, manganese, zinc, cobalt, nickel, titanium, barytes, strontian, lithium, fluorine, selenium, phosphoric acid and boracic acid. Besides these inorganic bodies are traces of resinous substances and organic acids, among which crenic and apocrenic acid have been detected, and, probably, formic, ambric, and benzoic acids. This, at least, is the result of analysis by M. Gottl. We are not aware whether it has been confirmed by any chemist of European fame.

The quantity of solid matter removed from the interior of the earth to or towards the surface, by the various mineral springs throughout the world, is very much larger than would at first be supposed. The quantity of carbonate of lime thus displaced and replaced is exceedingly great, and large deposits of it, occupying thousands of square miles and of great thickness, due entirely to this cause, are not unknown. Silex is also deposited very largely near hot springs, especially in Iceland. It has been calculated that the Carlsbad waters bring to the surface annually a quantity of sulphate of soda, that would yield 15,000 tons of the crystallised mineral. In the extinct volcanic district in the centre of France, which occupies but a small space, but where the number of springs is very large, the carbon contained in the carbonic acid gas emitted during a year, from the water that rises to the surface, cannot be estimated at less than 365 tons, while the quantity of solid matter, if the water were evaporated, would exceed 16,000 tons in the same time. It must be remembered that these waters are not at all remarkable for the quantity of solid salts held in solution, the average being assumed as about 350 grains to the gallon.

A consideration of the substances held in solution or suspension by water, as it emerges from the earth, is very essential to a right understanding of the part that mineral springs play in forming and modifying the earth's crust. It will be well to explain, briefly, the mode in which they appear, and their relative importance.

Of the gases, oxygen, hydrogen, nitrogen and ammonia, are all present either in a free state or in combination. Owing, no doubt, to the facility with which they combine with other elements, oxygen and hydrogen have not been detected alone. Nitrogen, on the other hand, is very common; especially in waters containing sulphur. Such waters almost always contain organic matter. Nearly the whole (82 to 87 per cent.) of the gases evolved from the springs at Aix-la-Chapelle, and about the same per-centage of the Wildbad Spring (Wurtemburg) consists of nitrogen. No doubt much, if not all, of this is derived from the atmospheric air carried down with the water, but some may also be due to organic matter present in the minerals that the water has traversed. Of the compounds of nitrogen, ammonia is found in the waters of Plombiéres. Its origin is by no means clear. It exists with iodine and bromium, in the waters of Coese, in Savoy. It has been remarked that ammonia is not present in water issuing from granite.* Traces of nitrous acid have been found in some springs, as at Giessen, where this product forms 2 per cent. of the binoxide of manganese, contained in the waters.

Sulphur is one of the substances widely diffused in mineral waters, and present in tolerably large quantities. Pure sulphur is occasionally, though rarely, deposited from sulphurous vapours in an efflorescent state, in the neighbourhood of volcanoes, both recent and extinct. Large quantities of native sulphur are deposited in beds of gypsum in Sicily, on the eastern slope of the Apennines, especially near Rimini, in Corfu, in Savoy, in the south-west of Spain, and in many other places. Sulphur springs are common in most of these localities. Incrustations of sulphur are found on the vaults of the old baths at the Bagneres de Luchon, in places where the water itself never reached. A milky appearance, or a black stain, are not uncommon marks of the presence of sulphur in mineral waters. Silica is found with sulphur in Iceland and elsewhere, but sulphate of lime (gypsum) is exceedingly common wherever sulphur exists in any quantity, either now in mineral waters, or formerly, where such waters have passed. Sulphuretted hydrogen is frequently set free from mineral springs, and appears in bubbles, which rise through the water, often coated with bitumen. Sulphuric acid is also not uncommon, especially near volcanoes. Very large quantities exist in the water issuing from some springs in central America, described by Humboldt. Upwards of 7½ millions of gallons of water, derived from the upper part of the volcano of Puracé, come down every day, in a stream called the *Rio Vinagre*, and this daily run of water is calculated to contain 40 tons of sulphuric acid, and upwards of 30 tons of hydrochloric acid.† Many other instances are recorded.

---

* Comptes-rendus de l'Institut, t. 42., p. 1269.

† Idem, t. 24., p. 398.

Fluorine has not been found free in mineral waters, but it is present combined with calcium, though in very small quantities. Phosphorus is also found in combination only, but it is very much more common. At Aix la Chapelle, some of the springs contain phosphate of soda and lithia, and fluoride of calcium. Arsenic is also widely distributed. It has been found in most of the Auvergne springs, in those of Wurtemberg, and elsewhere. In these springs the quantity is very small, but in Africa, near the ancient Utica, at the spring of Bon-Chater, there is a spring containing 72 grains of solid matter per gallon, of which 12½ grains consist of arseniates of potash and soda. The temperature of the water is 104° F. These waters are said to be inoffensive, and to be commonly used for drinking, both by cattle and men.

Boracic acid is a common and abundant mineral in thermal springs in certain localities in Tuscany, but it has hitherto been thought rare in mineral waters generally. It has been detected, however, at Luchon and other Pyrenean baths, and also at Vichy. It is, no doubt, widely distributed.

Silica is so very widely distributed now, and appears to have been so universally present during the whole of the earth's history, that we may well look for it in mineral waters, and be prepared to find large deposits of it, when such waters have been evaporated. It is chiefly hot springs, in the neighbourhood of volcanoes, that are rich in silica. Very often we find fragments of wood, and sometimes whole beds of vegetable matter, silicified. In the Azores, especially in the island of St. Michael; in the West Indies, in the island of Antigua; in Egypt, between Cairo and the Red Sea; and in some parts of Australia, similar changes are well known. The mass of silica thus accumulated on the earth is very large. In Iceland there is a deposit two leagues in length, and a quarter of a league wide, and in some places a hundred feet high, composed entirely of silica, derived from numerous boiling springs resembling the celebrated Geysers. In other places, a coating of silica, in others siliceous stalactites, have been described. The silica is generally deposited in the gelatinous state, hardening on exposure.

We have already alluded to the large quantity of carbon occasionally to be found in mineral waters, locked up in carbonic acid gas, and liberated as the water reaches the surface. Carbonic acid is indeed so common in mineral waters, and even in ordinary spring water, as to be almost universal, and it has been remarked that the more of this acid there is contained in the water, the greater is the quantity of alkaline bicarbonates. The presence of carbonate of lime, or limestone, in rocks of all ages, and the distribution of carbonic acid in the atmosphere, as well as in all cold spring water, and in the water of the sea, is a proof that carbonic acid has at all times played an important part in the construction and modification of the earth's surface.

Hydro-carbons, either in the form of gas, (carburetted hydrogen) or in the form of liquid or solid bitumen, abound in certain mineral waters, and in some places the liquid varieties issue from the earth like water, in continuous streams of very large quantity. These are sometimes, but not always, connected with water. Certain waters also are very bituminous. Some of the Auvergne springs are so; while, on the other hand, some bitumens contain a marked per-centage (sometimes 20 per cent) of water. A considerable quantity of oxygen gas is present in these cases. Remarkable instances of bitumen and inflammable gas, rising through and with water, are seen at Baku, on the Caspian, in the pitch lake of the island Trinidad, and in Zante. Bituminous springs rise through the sea on the east coast of Zante. Other cases are known where the vapour of these bitumens, issuing from the earth, readily takes fire, and burns for a long time. The bitumen has often impregnated the sands and limestones, and other absorbent rocks, to a considerable distance on each side. At Paterno, in Sicily, a mass of basalt is loaded with naphtha. Since the year 1854, various places in North America have yielded enormous quantities of *rock-oil*, a variety of petroleum greatly used for burning. It issues in strong springs, generally reached by boring. The oil often rises into the air in a jet like a fountain. In one case, it was thrown to a height of 24 feet above the surface, drowning the whole neighbourhood. From a few springs the supply has amounted to upwards of a hundred millions gallons in a year. Although not strictly connected with springs of water on the spot, these springs of petroleum belong to the same class of phenomena, and are properly noticed in this place. Chloride of sodium (common salt) accompanies such springs, and the long known phenomena of naphtha and petroleum springs, in Palestine and northern Asia, appear to be of the same nature.

Potash and its salts, though very widely disseminated among rocks, are generally absent in mineral waters, soda taking its place. Though occasionally met with, potash is probably less frequent than lithium. Nitrates of potash, however, exist in water in India, and also in Hungary, on a somewhat larger scale. The latter case is very interesting, as it seems impossible to refer the potash to organic origin, most of the springs issuing from a depth of 30 feet, and the group extending over a very wide space, throughout which all the wells sunk yield this salt. These springs also have been known for centuries, and there is little organic matter in their vicinity. California also yields potash in thermal springs.

Lithium, long regarded as a rare substance, is now found by the aid of spectral analysis, to exist in most mineral waters. In some it is extremely abundant; and in a hot spring issuing in a mine in Cornwall, the proportion is exceedingly large. Rubidium and Cæsium, two new metals, have recently been detected in certain mineral waters, and Thallium is found under conditions which render its existence probable in a similar position.

We have mentioned that the salts of soda are common in mineral water. The salts most common are chloride of sodium, and carbonate and suphate of soda. In some hot springs silica is present in large quantities with soda. Carbonates of soda (bicarbonate and sesqui-carbonate) abound in many springs. Thus the waters of Vichy, if evaporated, would yield upwards of 100 tons of this salt per annum, and other springs at an equal rate. Some springs contain the sulphate instead of the carbonate. The springs at Carlsbad contain 190 grains to the gallon, those of Cheltenham 150, and those of Pullna nearly 1,500 grains per gallon. Deposits of sulphate of soda, no doubt from mineral waters, sometimes become absolute rocks, as at Lodora, on the frontiers of Navarre and Old Castile, and on the shores of some curious lakes in the Crimea. Common salt is found in small quantities in most mineral waters. Some are almost saturated with this mineral, containing more than two pounds weight of salt to the gallon.

Next to the salts of soda those of lime are the most abundant in mineral waters, and of these the carbonates may be considered as universally present in some proportion. Calcareous deposits from water are equally common, and where mineral waters contain much carbonate of lime the neighbourhood is generally more or less coated with travertin. Perhaps in no country are springs of this kind more remarkable than in Tuscany, where their number is altogether incalculable. In one place where the water runs into a pond a deposit of nearly 30 feet in thickness has been formed within the last twenty years, and in small boxes, into which the water is allowed to drop on intaglios and evaporate slowly, cameos are formed by incrustation in a period of about four months. The same result is obtained in Auvergne.

At Carlsbad the calcareous crust formed around the issue of the Sprudel spring was, many years ago, observed to interfere with and greatly diminish the yield of water, and at length was partially broken through by the water at the beginning of the last century. Under these circumstances it was thought advisable to pierce the whole in order to increase the yield from the spring, and give a freer access to the water. It was found after piercing one crust that there existed a large cavity full of water under pressure. Below this was another, and this also being pierced, the water issued with increased force. Below this again, however, was a vast reservoir, and there were no means of ascertaining further the extent of the formation. The crusts were from one to two feet thick, and not immediately below each other. The same spring has several outlets over a considerable area. In Algeria, at a place where are springs loaded with carbonate of lime, a large area is covered with conical hills from 5 to 18 feet high, formed round the different outlets that the water has made, and numerous similar examples might be given.

Large deposits of sulphate of lime from springs of mineral water are common in many parts of the world, and are probably due to the issue and evaporation of waters containing this mineral. Gypsum, sulphur, rock salt, and carbonate of lime, are very often associated together. Fluate of lime, though in small quantities, is common in certain localities, though much less abundant than the sulphate. The Vichy waters, among others, contain this salt. Phosphate of lime is distributed in about the same proportion as fluate.

The salts of magnesia are next in importance to those of lime, and are very widely distributed in mineral springs. Bicarbonate is the most common—sulphate is hardly less so. Sea water contains from 150 to 500 grains in the gallon The Cheltenham waters have a small quantity (about 100 grains), and the Seidlitz waters, in Bohemia, an extreme quantity (2,000 grains per gallon). Some of the springs at Pullna, also in Bohemia, are still more rich in this salt.

Alumina, combined with silica and other elements in double salts, is common in most springs in small quantity.

Of the metals, both manganese and iron are very commonly distributed in the waters of mineral springs. The former metal is generally in small quantity, but at Carlsbad, at Popayan in Mexico, and in Algiers, there are waters more than usually rich in this element. Iron is found everywhere. All the chalybeates—so numerous in every part of the world, are of this kind. The quantity is not often large, though occasionally it is sufficiently so to produce ferruginous deposits and incrustations in very large quantity. Bischoff has described the Eifel springs, the waters of which bring nearly two tons of iron to the surface every twenty-four hours. The iron in water is generally, but not always, in the state of peroxide.

Cobalt and nickel are said to have been found in mineral waters at Boulou (Central France). Oxide of tin is said by Berzelius to have been found by him in some springs in Bohemia. Titanic acid has been recently detected in those of Wildbad-Gastein. Copper is very often met with. Lead is not unknown. Silver and gold are known to be soluble in water, and must be present in certain springs. The latter has been detected by M. Laur in some springs in California.

One of the most remarkable and interesting facts with regard to mineral and thermal springs is that they exhibit on analysis unmistakeable evidence of the presence of organic matter. The form assumed by this organic matter is that of a glairy substance, not referrible with certainty either to the vegetable or animal kingdom. It is called by chemists *glairine*, *baregine*, or other names, and it appears to differ in different springs. So large is the quantity that the mother liquor from the salt works at Bex, in Switzerland, where there are strong saline springs, has yielded sufficient to show a carbonaceous residuum after calcining. This substance is not easily obtained, as it is destroyed by evaporation, but it can be detected by the microscope. The waters containing it are soft. It is chiefly abundant in those waters that appear to have least to do with superficial drainage, and especially in sulphurous springs. The development of Confervæ in such waters is so rapid that at Plombières, where one of the springs is particularly rich in this substance, it is necessary to empty the large swimming bath every week in order to cleanse it from the accumulation. The substance is amorphous, and its colour is occasionally black, red, or violet.

It has been stated that within the limits of human observation the temperature of water coming from considerable depths through natural fissures is, in each particular spring, invariable; but there is no doubt that changes may occur, and it is certain that in some instances they do. There are many reasons for this, even assuming that the temperature of the earth below remains constant. In some cases the volume of water may be increased, and the mean temperature diminished by the influx of cold waters or melted snow from near the earth's surface. Extreme and long continued drought may at another time remove parts of a supply that belong to the upper strata and allow the deeper waters to rise in diminished volume, but increased temperature. Accumulations in the channel through which the waters pass, either by some deposit from the water itself or by the accumulation of foreign substances brought in, may entirely alter the circumstances under which the water comes to the surface, or may stop it altogether at the usual outlet. The breaking in of the roofs of caverns in the interior of the earth, the disturbance of the strata by earthquakes, and other causes, may also act to produce great changes.

Instances are not wanting of all the accidents and disturbances here alluded to. Thus, within a period of thirty-three years the springs of Las Trincheras, in Mexico, described by Humboldt, were found by Boussingault to have increased several degrees in temperature. During this period there was a great earthquake destroying the town of Caraccas. About the time of the great earthquake of Lisbon, in 1755, the waters of Aix, in Savoy, became colder, and deposited a bluish sediment, while those of Luchon increased in temperature. Some of the springs in Central France were augmented in volume but diminished in temperature.

In 1854 there was a succession of small vibrations of the earth in the Pyrenees. During this time at Gazost (Bagnères) there was a large quantity of organic matter emitted, of black colour and loaded with sulphuret of iron. The same phenomenon was observed at the "Cæsar" spring at Cauterets, where the temperature was increased. At Barèges one spring increased in temperature from 64½° to 82½° F., and its volume was more than doubled. Besides these instances, referrible to known disturbances, the waters of certain springs at Plombières occasionally vary without apparent cause from 3° to 18° F. in their temperature.

Intermittent springs occur in many parts of the world, and under various circumstances. The intermission may be more or less regular, or quite irregular. The former cases of intermission are generally due no doubt to the existence of interruptions of strata forming syphon tubes. The water passing through natural channels must occasionally enter and fill open spaces in the interior, forming closed reservoirs, and these may have outlets only by channels, which, though they communicate with the lower part of the cavity are bent and curved upwards before reaching a lower level, by which their contents are ultimately discharged. So long as the water draining in from above, or through crevices in the walls, does not reach the level of the highest point of the curve it is not delivered by this passage at all. When it does, and the delivery begins, it is continued till the cavity is emptied to the point where the channel opens into it.

If there is a narrow but insufficient channel besides this syphon tube there will be a constant discharge, which is occasionally very much increased, and then as suddenly diminished. If the reservoir is deep and the supply reaches it slowly, it may be a year or two before a change in the quantity entering from the surface, from increased rain-fall, produces an impression. Thus it may be that there is no discharge or a very small one in a wet year, and an abundant discharge during some subsequent very dry season. All these, and many other peculiarities and modifications of water supply from springs, are perfectly consistent with their original source. They are not the less derived from the rain-fall of the district, and their channels are still those naturally existing in the rocks through which the water passes.

A very curious instance of intermission is exhibited by one of the springs at Kissingen, in Bavaria. The temperature of this spring is generally 64° F., and the water contains 810 grains of common salt, more than 200 grains of chloride of magnesium, and as much sulphate of soda, besides other salts, making a total of 1,500 grains to the gallon. It usually exhibits a peculiar bubbling or effervescence, but after certain intervals, whose duration is known, the effervescence of the waters becomes less considerable, and the jet diminishes till it is almost altogether suppressed. This lasts from 17 to 24 minutes. After this time the water once more effervesces, but gradually, and it takes 30 or 40 minutes to rise to its previous height. In the course of six years, during which the phenomena have been carefully observed, the number of intermissions was 857 each year. Of the whole time the level of the water was lowered during 3,521 hours, and at its ordinary height 5,239 hours. The period of repose averages 8 hours 3½ minutes, in each 24 hours, and the quantity of water issuing from the spring in a given time is invariable.

Careful observations made at Vichy have shown that the quantity of water issuing from one of the principal springs (Source du Parc) varies inversely as the quantity of carbonic acid gas in the water, and this is greater or less, according as the pressure of the air increases or diminishes. The increase is greater *cœteris paribus* with north or north-east winds, and the diminution greatest with south-east, south, and south-west winds. In the springs in the Pyrenees similar observations have been made. Other remarkable cases of the sudden increase of springs have been recorded during violent storms, when the barometer has fallen to an unusual extent. There can be little doubt that careful observations would show similar results generally. In many places where petroleum springs occur there is a similar alteration of quantity, according to the state of the weather.

Changes in the supply from springs, owing to the gradual choking up of the channel, by which the waters rise to the surface, are not unfrequent. At Vichy, in the year 1808, the spring named "Grande-Grille" yielded 85,000 gallons of water at a temperature of 106° F. In 1809 the quantity was reduced to 75,000 gallons at 104°. In 1829 the yield was only 60,000 gallons, and the temperature 100°. Lastly, from 1843 to 1853 the volume of water was lowered from 21,000 to 17,000 gallons, and the temperature from 94° to 92°. On the other hand, in the winter of 1853 a mass of travertin (arragonite) was removed from the course of the issuing waters, and the yield was at once increased to 340.000 gallons at a temperature of 107°. A kind of exdlosion will sometimes take place in springs thus choked up if there is no natural outlet in some other direction, but this is very rarely the case, and the choking up of one spring is generally only preliminary to the breaking out of the same spring in some other direction, and the formation of a fresh deposit of incrusted salts.

A remarkable change sometimes takes place in the mineral contents of springs. Thus at Plombières the gaseous contents of one of the springs, carefully taken, show a difference at different times of from 0 to 1½ per cent. of carbonic acid gas, and from 2 to 3 per cent. of oxygen. At Clermont a spring which once deposited silica now only yields hydrous oxide of iron. The sulphurous waters of the Bagnères de Luchon change their composition very greatly, according to the state of the barometer, the season of the year, the prevalence of snow in winter, and other causes. Some waters periodically deposit oxide of iron. The spring of Saxon, in the Valais, (Switzerland) is sometimes rich in iodine, and sometimes hardly contains a trace. This appears to be connected with emanations of certain gases, which bubble up through the water at intervals.

Water thus circulating through the earth, making its way through strata, running down into crevices and fissures in one place, and rising through open channels to the surface in another;—varying in temperature, and varying greatly in mineral contents;—cannot but produce great influence on the rocks it traverses. That it is chiefly by such means that metals and minerals of almost all kinds, and in all conditions, have been deposited in mineral veins, there can hardly be a doubt, and it is equally certain that by such means deposits once made have often been greatly modified, altogether removed, or replaced, atom by atom, by other minerals crystallising naturally in different shapes. Thus it is that strata have become metamorphosed, and organic bodies preserved permanently by being sealed up and converted into durable stone. It is by the agency of water in its course through the earth that the work of change on all accumulations of every kind is rendered easy and effectual. Water is, indeed, the recognised means by which the various physical forces, or rather the different forms of physical force, can most readily act. It is always present—it makes its way through every rock—it forms part of every rock—it conveys fresh material to, and removes part of its substance from, every rock that it traverses. Water performs the same part in the economy of the world that blood does in the animal frame. Its use, as seen on the surface, is as nothing compared with its value in circulating through air and earth altogether out of sight.

In looking at the origin of the very large supplies of water present in the earth, and often emitted under peculiar circumstances with great force at a very high temperature, some writers have been led to speculate on the possibility of there being an independent source of water in the interior. There seems no need for such an assumption. Certainly the quantity of rain entering the earth, and not immediately evaporated, is exceedingly larger than that yielded by all known springs and that conveyed to the sea by rivers, and needs great evaporation, not only from the vegetable soil but from the surface of rocks apparently dry, to preserve a balance. That such balance exists, and is perfect, is certain. There is no proof whatever that either the relative level of land and sea or the quantity of water on the surface has, throughout all geological time, shown any variation.

PART THE FOURTH.

AIR.

CHAPTER XII.

THE ATMOSPHERE.

THE earth and sea are uniformly covered with a great but unknown thickness of gaseous matter, which is called the atmosphere. Being gaseous, it consists of material particles not held together by the force of cohesion, but it is not the less made up of atoms capable of forming solids. A hundred parts of pure atmospheric air, in a dry state, contains 23 parts by weight of oxygen and 77 parts nitrogen. One hundred volumes of dry air, under ordinary conditions, contain, however—

Nitrogen	79·12 volumes.
Oxygen	20·80
Carbonic acid	·04
Carburetted hydrogen	·04
Ammonia	Trace.

The air being elastic in a very high degree, and retained close to the earth by attraction of gravitation, is most dense or heaviest when in contact with the earth, and gradually less and less dense as it is farther from the surface. At the sea level the average pressure of common air equals that of about 30 inches of mercury, or 34 feet of water (equivalent to nearly 15 pounds on every square inch of surface). At the height of 12,000 feet above the sea—an altitude surpassed by many of the peaks of the Alps—the density is halved, or one volume is expanded into two. At such elevation, the column of mercury in the barometer, which measures the atmospheric pressure by balancing it, would therefore mark 15 inches instead of 30; and the actual pressure of the air on each square inch of the earth's surface is reduced to 7½ pounds. The density is again halved at a further elevation of the same amount. Thus, even below many of the highest peaks of the Himalayas and the Andes, the barometer would stand at 7½ inches, and the atmospheric pressure would be reduced to 3¾ pounds on the square inch. At an altitude of 45 miles, at this rate of reduction, the air would scarcely exhibit any sensible density or pressure; but it does not follow, nor is it probable, that there is no part of the atmosphere above this elevation. On the contrary, there is much to render it likely that an atmosphere,—capable of acting on light, of interfering with and causing sensible friction on foreign bodies coming in contact with it, and of carrying on all the ordinary functions of atmospheric air, though with diminished intensity,—exists at a distance of more than a hundred miles above the sea level.

On the other hand, were the air inelastic and everywhere at the same density as at the sea level, its total height would not much exceed five miles; and as 100 cubic inches of dry air, at the temperature of 60° F., and under the pressure of 30 inches of mercury, weigh 30·83 grains, the weight of the whole body of pure dry air may thus be calculated. It has been estimated to amount to 4,850 millions of millions of tons. Such is the quantity of matter, in an invisible and intangible state, floating over the surface of land and sea, and fitting the earth for the habitation of organic beings, by enabling a circulation to be effected on which all life on the globe depends.

Mixed with the dry air (not chemically combined) are many other substances. Among these, aqueous vapour, or the vapour of water, is the most important. The proportion varies greatly, according to the temperature. Besides gases, such as carbonic acid gas and carburetted hydrogen, of which a calculable proportion has been determined, and ammonia, of which there is always a trace, we must also admit the presence of sulphuretted hydrogen, sulphurous, hydrochloric and nitric acids, the odoriferous principle of plants, the principle or matter called ozone, the miasmata of marshes, and various gases liberated from volcanoes. There is also some quantity of the following bases:—potash, soda, lime, magnesia, iron, manganese. These are known. but there may, perhaps, be many others.

All the ordinary phenomena of water are affected by the atmosphere, partly owing to the incessant though variable pressure of the air, partly to the fact that air and water are mutually capable of absorbing and retaining each other. There is no water that has long been exposed that does not contain a certain quantity of air. There is no air in a natural state that does not contain aqueous vapour. But the quantities thus held vary extremely, and their effect on the conditions of life on the globe vary with every change.

The gases that form atmospheric air are not chemically combined. They are mixed mechanically, and each produces an independent effect. And although one gas is often somewhat heavier than another or others with which it may happen to be mixed, there is no tendency in the gases to separate, or even to become permanently changed in any way, as by the practical absorption of one at the expense of the other when they are capable of combining. Taken from whatever part of the world, or from whatever elevation;—brought from the highest mountain, from the sea side, or from the centre of the most thickly-wooded glade, or obtained from the most densely-populated town,—the general proportion of oxygen and nitrogen is very nearly the same. It does not seem easy to account for the perfect balance thus kept up, but of the fact there is no doubt.

But the pressure of the air, the height and weight of the atmospheric column, change exceedingly. These matters vary not only at different elevations, but even on the same level and at the same time, in places not far apart, they may be quite unlike. At the same spot the barometric pressure often alters from day to day, and even from hour to hour. These oscillations are of two kinds: some are regular and seasonal; the others are irregular, and depend on changes going on at a distance. In certain latitudes the oscillations are small, but regular; in others they are large. Where they are smallest and most regular, the seasonal changes are best examined. Some are annual, some diurnal. The daily oscillations attain a maximum twice daily (at about 9½ A.M. and 10½ P.M.), and a minimum also twice (at 4 A.M. and 4 P.M.). Within the tropics these elevations and depressions may be observed very readily, and are quite undisturbed by and independent of the differences caused by storm and by other irregular causes of derangement. Towards the poles they cease to be observable, and perhaps cease to exist, or become inverted. The amount varies, but is generally greatest at the equator, where such oscillations attain a range of about one-tenth of an inch.

The seasonal oscillations are generally regular. In warm climates, north of the equator, the mean pressure diminishes gradually from winter to summer. On the east coast of the old world, from December to June—in India and at Cairo, from January to July—the pressure diminishes, though very little. In the West Indies, January to August are the months of minimum. The range, however, is only about 0·63 inches. In the north temperate zone there are two minima, one near each equinox. There are corresponding maxima in summer and winter, but the summer maximum is lower than that of winter.

The effect of alterations of pressure or density of the air is greatly felt in reference to temperature. Air, when dry, allows heat to pass through it without absorbing more than a very small proportion. It hardly becomes warmed by the passage of any amount of heat rays. We have already alluded to this fact in a former chapter, and it is one of extreme importance. When heated, it expands so rapidly and largely as to produce immediate results; but it is not heated by radiant heat. It is heated by conduction, or contact with heated matter, by friction of its particles among each other, and also by compression. On the other hand, it is cooled by expansion. These facts are proved by experiment. Thus, by the sudden compression of air by a piston, it is possible to set tinder on fire. By the sudden expansion produced by admitting air into an exhausted receiver, ice may be formed. Heat radiates through clear air into space, but it immediately ceases to radiate when aqueous vapour is present in the air in sufficient quantity.

An important effect of altered pressure of the air is a change of the temperature at which water passes into a state of ebullition. It is well known that near the sea, and under ordinary circumstances, the thermometer stands at 212° F., when placed in water that actually boils. It is, however, certain that the same liquid would pass into vapour at a very different temperature in a state of vacuum, for the degree of pressure on the surface greatly affects the operation. Thus, as the pressure of the air diminishes, the heat at which ebullition takes place also diminishes. But we know, that in ascending a mountain the pressure of the atmosphere diminishes, and therefore also the boiling point becomes lowered. Professor Tyndal relates, that on the summit of Mont Blanc he found that water boiled freely at 184·95° F., being about 27° F. lower than at the sea level. The lowering of the boiling point is at the rate of 1° F.

for every 590 feet of ascent; and elevations can be estimated approximately by this method.

The temperature of the air diminishes as we ascend into the atmosphere, though not with perfect regularity, and it becomes extremely low at great elevations. This is due partly to the great expansion of the air in its upper part, and partly to the diminished power of the air to retain any large quantity of the heat radiating through it. The air, at great elevations, is also comparatively dry, as the atmosphere of aqueous vapour appears to reach only to a very small height in comparison with the whole atmosphere. This is more especially the case when the air is clear and radiation goes on rapidly through it. Judging from the partial but exceedingly valuable experiments made by Mr. Glaisher in balloons, the diminution of temperature in our latitudes may generally be regarded as diminishing according to a definite law. Thus, the depression is 7·2° F. for the first thousand feet, but only 5·3° F. between the first and second thousand, and still less for greater heights. From 14,000 to 15,000 feet the diminution amounts only to 2·1°, and from 28,000 to 29,000, it has become reduced to 0·8° F. There are, however, occasional strata much warmer, and others cooler, than strictly belong to the elevation.

The relations of the air to light are not less remarkable or interesting than those that refer to temperature and pressure. Air transmits a very large proportion of the solar rays that fall upon it under favourable circumstances, but it always absorbs or intercepts some. Thus, of 10,000 rays of light entering the atmosphere, it appears that upwards of 8,000 arrive at a given point, if they fall perpendicularly through clear air. If the angle be 50 the number is about 7,000, while it is less than 3,000 if the angle be as small as 7°. Lastly, it is estimated that only five rays out of the ten thousand make their way to the earth through a horizontal stratum of air. It is familiar to every one that the face of the rising or setting sun can be readily looked at by the naked eye, whereas its noon-day effulgence would immediately produce blindness. In the case of reflected and distant light, a large number of rays are always reflected and dispersed, appearing to be absorbed or resolved into some other form of motion in passing through the matter that makes up our atmosphere. This is the case even under the most favourable circumstances, while under less favourable conditions hardly any rays reach the surface; so that such objects are imperfectly distinguished or not seen at all.

But the rays that do not fall vertically are not only absorbed to a larger extent but they are bent aside in their course. This bending is called *refraction.* It is greater in proportion to the density of the transparent material through which the light passes; and thus, in the case of atmospheric air, whose density is constantly and regularly increasing from the outermost and thinnest film of the atmosphere to the earth, the ray of light is bent in a curve, so that the direction of a ray at any part of its progress appears to be that of a tangent at that point to its actual course. Lastly, all rays of white light entering the air being made up of coloured rays in certain proportion, which are differently affected by the air through which they pass, the light that reaches the earth is more or less tinted with colour, according to the quantity of air passed through and the quantity of vapour in the air.

The course of a ray of light in its progress to the earth may be thus briefly described:—

The ray falling on the uppermost limits of the atmosphere meets there an elastic, transparent gas, in a state of extreme tenuity. On first emerging from the luminiferous ether into this more dense medium, a small part is reflected back into space, and a part is dispersed and absorbed, but the rest, as it enters, is somewhat bent aside from its course. As it proceeds onwards the medium becomes constantly more dense, and the ray becomes more deflected, while reflection, dispersion, and absorption continually take place. The light that, in the absence of the atmosphere, would have arrived in a straight line from the sun, leaving all surrounding space dark, is dispersed through the surrounding medium, which is more or less illuminated. Of the portion reaching the earth, part is absorbed, and the rest lights up the solid surface. This latter part being reflected by the various substances on which it impinges, either passes back into space or is converted into some other form of motion. The partial illumination of the very young moon is produced by light thus reflected from the earth. This description is applicable, whether we regard the ray of light as material or as a group of undulations in an ether pervading all space.

In consequence of the partial dispersion of light by means of the atmosphere, we obtain all those varieties of half-shade which enable us to make use of organs of vision constructed as are our eyes. Were it not for this, we should constantly have either full broad and dazzling light, or deep black shadow and impenetrable darkness. The objects in nature actually emitting light are few, and with the exception of the sun they are only available at intervals, except by artificial means; so that in those parts of the world in which, from their position, the sun is long absent in the winter season, or where clouds obscure its face for a large part of certain seasons, the inhabitants would have to exist in total darkness. It is in consequence of the quantity of light that is dispersed and reflected within the atmosphere itself from the molecules of air, or from the particles of aqueous vapour always present in the atmosphere, that there cannot be found at any hour of the longest night, or at any season, a total absence of light. Owing to the same cause there are no sudden transitions from darkness to light or from light to darkness, such as if they occurred would be injurious to our organs of sight.

The ordinary phenomena of twilight will illustrate this fact. It is in the parts of the earth where the nights are longest, and where the darkness of winter would be uninterrupted by a single ray of light from the sun, that the light is continued in twilight for the longest time after the sun has set and before it has risen.

During a fine, clear, calm winter's day, in high latitudes, as the sun approaches the horizon the sky becomes yellow and red, while at the zenith, or just overhead, it is whitish and less clear than during the day. A warm red tint often prevails, and may be observed long after the sun has disappeared, and glorious but fleeting colours may be watched as the clouds form in layers or masses, apparently following the sun's course. For hours after the body of the sun is below the horizon the light of the sun, shining on the higher portion of the atmosphere, is refracted or reflected, and continues to give some light to the regions where direct sunlight has ceased. This twilight, as it is called, is repeated in the morning; and thus much of the earth becomes habitable that would otherwise be utterly unadapted for the development of life. Other partial illuminations of the sky in high latitudes are obtained; but the chief source of the light in those parts of the earth must certainly be the refraction, the reflection, and the dispersion of the rays of the sun as they enter and advance through the atmosphere. In the tropics there is hardly any twilight, darkness almost immediately succeeding and preceding full sunlight. The long nights of winter within the north polar circle are illuminated by almost incessant auroræ, and this is also probably the case within the Antarctic regions. The zodiacal light is another source of illumination. The subject of the twilight, and also that of the magnetic storms, of which the aurora is an indication, is one of considerable interest, as leading to a knowledge of the final limit of the earth's atmosphere.

The twilight by reflection is limited to the position of the sun, which ceases to give light to the vapours and other substances in the air when more than 15° below the horizon. The more obliquely he descends, however, the longer he will take to reach this position; and thus, in high latitudes, there is at all seasons a longer twilight than within the tropics, where the sun's path is almost vertically through the zenith at noon, and it appears to describe a great circle.

The ordinary phenomena of refraction as exhibited in the atmosphere, are greatly affected by the quantity and distribution of the aqueous vapour. Under certain circumstances, and in certain conditions of the air in this respect, very curious instances of complicated refraction and reflection take place. Optical illusions are thus produced, some of which are difficult of explanation. The word *mirage* has been applied to these phenomena by the French, and there is no exact synonym in our language.

The illusions of mirage differ according to circumstances. They are most remarkable where, either from heat or cold, (generally in the vicinity of water), distinct strata of aqueous vapour are formed in the atmosphere, or where variations of temperature and, therefore, of density are extreme. Thus on the coasts of Italy and sometimes in England, in the wild mountains of Scotland and in the Hartz, in the burning desert of Africa and in the frozen seas of the poles, these phenomena have been recognised. They are sometimes exceedingly strange and even startling in their character, presenting an image of what really exists, but is entirely out of the range of ordinary vision. Sometimes, also, they exhibit parts of objects broken, distorted, and out of place; sometimes they confuse, in a singular manner, the true outlines of objects. Occasionally they present a gorgeous and fairy-like spectacle—superb palaces, with their balconies and windows resting on the bosom of the broad ocean; lofty towers near them, herds and flocks grazing in wooded valleys and fertile plains, armies of men or single figures on horse-back, or on foot; multiplied fragments of buildings, columns, pilasters and arches; ships and churches, all mingled in wild confusion, or shown in clear outline as moving shadows, or fringed with red, yellow, or blue light. The *Fata Morgana*, seen in the Straits of Messina, the Spectre of the Brocken, and a number of other local names have been given to instances of mirage. Singular effects of refraction through heated air are seen sometimes in the neighbourhood of volcanoes, whence hot vapours are rising continually.

There appear to be three distinct causes of this curious phenomenon—vertical reflection, horizontal reflection, and that variety of refraction which may be called suspension, inasmuch as it appears to lift out of their places the objects exhibited by its means.

The most simple cause, that of reflection, often produces its effects in hot sandy deserts, after the soil has become heated by the sun. In such cases the prospect seems bounded by a sheet of water, and underneath each object, such as a village or a clump of trees on a small eminence, a reflection is seen as if from water. A singular effect of this kind is described by Captain Maunday, as seen in India. "A deep, precipitous valley below, at the bottom of which I had seen one or two miserable villages in the morning, bore in the evening a complete resemblance to a beautiful lake. The vapour which played the part of water ascended nearly half way up the sides of the vale, and on its bright surface trees and rocks were distinctly reflected."

In horizontal reflections the image is moved as it were sideways. In this manner Dover Castle has been seen complete from near Ramsgate, although there is between the two places a hill which, under ordinary vision, intervenes, and cuts off part of it. Thus, too, the French coast, with its cliffs and villages, has been seen from Hastings, although the distance is sufficiently great to render it impossible to come within ordinary vision. A person standing on a cliff facing the sea, with no other cliff in sight, has seen the cliff on which he was standing, together with his own figure and that of various objects by his side, reflected as if from a mirror. This has been noticed at Brighton, at sun-rise, in the month of November, during the existence of a dense fog on the sea, some yards in height. In the month of August, again, about 2 P.M., a young lady on a hill in Wales saw, on one occasion, her own image reflected from a wet spot a few yards from her, on which a thin mist was rising. The image reflected was sufficiently distinct to show colour, and was seen by others seated in a carriage at a little distance as well as by the lady herself.

The phenomena of suspension are even more remarkable. The simplest example is what is called "looming," very often seen at sea. The image in this case is unnaturally large, and seen immediately above its true place. This happens in the case of sea fog, and is very deceptive, as a rock may assume the appearance of a lofty cliff. Often it is inverted. Captain Scoresby describes that he, on one occasion, distinctly recognised his father's ship at sea, by its inverted image in the air, although the distance between the two ships was as much as thirty miles, and the ship was, therefore, far below the horizon of the place from which it was observed.

All these appearances and a multitude of others, modifications of them, that have been observed and described, depend on the existence of different strata in the lower part of the atmosphere, and this difference may be occasioned either by heat or aqueous vapour. The air may be warmed by the heat received from a plain or mountain side, either from the sea or the land, and the heating may take place in such a way as to produce either vertical columns or horizontal strata of vapour. Thus mirage may occur in very different situations, in any part of the world, and with the most varied appearances. It is, also, evident that any cause which re-establishes the equilibrium of density in the different portions of the atmosphere must cause the illusions of mirage to vanish. Calm is essential to the phenomenon, but this calm may be the immediate precursor of a tempest. Thus, under some circumstances, mirage itself comes to be regarded as symptomatic of change in the weather.

The colour of the atmosphere depends on the quantity of aqueous vapour contained in it in proportion to the temperature. Near the earth the sky in clear weather is blue, tending to shades of grey on the one hand and the deepest indigo on the other. The true cause of the azure colour, so characteristic in certain countries, is probably due to the colour of the water contained in it. It would seem from experiment that pure water, aqueous vapour and ice, all absorb the same class of rays, and thus the colour of all is alike. The air deepens in tint at great elevations, and becomes almost jet black, or colourless, at the tops of high mountains or in the upper regions of the atmosphere reached during balloon ascents.

The breaking up of the rays of white light into coloured rays is an optical phenomenon already explained, and it does not belong to our present subject. It is, however, necessary to allude to it in reference to certain atmospheric appearances of considerable interest. The colours of the clouds and the sky, the occasional rainbow, the halo that often surrounds the moon, parhelia or false suns—all these are dependant on the breaking up of the light that comes from the sun by the particles of water contained in the air. Of all these the rainbow is the most brilliant and remarkable. It is a portion of a circle made up of concentric bands of coloured light arranged as in the solar spectrum, the lower or innermost band being violet. This bow is visible only when the sun or moon is shining, and when rain is at the same time falling, the spectator being placed with his back to the luminary, and observing the falling rain. Outside the principal bow a second, somewhat fainter and with inverted colours, is sometimes seen. Much more rarely a third bow may be distinguished, yet fainter, and with the colours in the same order as the first.

The cause of the rainbow is as follows:—A ray of sunlight entering a drop of water as it is falling towards the earth is refracted as it enters, reflected from the inside of each drop opposite the point at which it enters and again refracted on emergence. By these refractions and reflection the ray is broken up, and only a part or one colour will reach the eye of the spectator. The same being the case with other drops the eye will see only a band of coloured light, having an apparent breadth about equal to four and a half times the sun's apparent diameter in the case of the inner bow, and an outer band about half as large again.* Rainbows are sometimes seen in waterfalls, and even in fountains, where the spray produced by the fall acts the part of the drops of rain.

The atmosphere allows the rays or waves producing light to pass freely through, and interferes but little with their progress, but its own component atoms are subject to waves or vibrations propagated through it much more slowly, and recognised by our sense of hearing. All sound is the result of such vibrations of particles of air. The motion consists, not in the shifting of the atoms bodily in space in the direction of the advancing sound, but in producing oscillations backwards and forwards, owing to the free condition of the atoms and the ready transmission of motion from one to another. All sound is connected with and communicated by vibration, and, indeed, consists of it, but water and solid matter also transmit sound readily, some objects even more rapidly than air. The transmission of sound is, however, checked and interrupted in passing from. one medium to another, and it is only through the atmosphere that it is conveniently conveyed. From the nature of the case sound cannot travel through a vacuum.

---

* These proportions and the mathematical proofs of the phenomena of the rainbow will be found in optical works.

The velocity of sound through the air is uniform and quite independent of its loudness, but whatever increases the elasticity of the air, accelerates the rate of vibration. Thus sound travels faster in warm weather than cold. At the temperature of 62° F., the speed is 1,143 feet per second, while at the freezing point (32° F.) the rate is reduced to 1,089 feet in the same time. It is an interesting fact, and a curious illustration of the identity of heat with motion, that the rate of speed of sound is faster in practice than would appear from the calculated formula, unless the formula be corrected by allowing for the increased rate of progress, in consequence of the heat, resulting from the compression of the air during the transmission of the wave. The actual rate at which sound travels is thus about one-sixth greater than it would have been if the temperature had remained unaltered, during the compression of the atmosphere, produced by the advancing wave.

The atmosphere is absolutely essential to the various forms of life that exist on the globe, so that not even the simplest form of animal or vegetable organisation could perform its functions, but for this all-pervading medium. The phenomena of physical life may almost be said to consist of chemical changes, induced by the combination of the oxygen of the atmosphere with carbon derived in some way from the earth. Even in such animals as the medusa, a jelly-fish growing occasionally to an enormous size, and weighing many pounds, but not containing more than a few grains of any obtainable solid, the relation of the material particles and the history of life seems still the same. In them, as in the lichen on the rock,—in the tree, as in man, the actual and essential phenomena of life are the same. By the oxygen of the atmosphere combining with carbon, life, as well as heat, is evolved. By help of air, the marine animal and the aquatic plant, as well as the quadruped and the tree, are enabled to live, and perform all those various functions that belong to them. The atmosphere is, in this respect, an essential feature in the constitution of our globe, and however we may speculate on the possibility of the existence of sentient and intelligent beings in other planets, we cannot form a notion of what that material life may be, which is independent of air.

There are many very curious results of atmospheric action on light, besides its dispersion and refraction. *Polarisation* is one of these, and must be briefly referred to here as being not without importance in the economy of nature, although it belongs but to a small extent to Physical Geography. When a beam of light is admitted into a dark room through a circular aperture, and reflected from a mirror, it might be supposed that the reflection would take place in the same way, and with the same intensity, above or below, to the right hand or to the left, according to the position of the reflector, and that the beam of light would be unaltered. This is not exactly the case, for if it be reflected at a certain angle, varying with the nature of the reflecting surface, it will acquire fresh properties, as if it became rather like a flat ruler than a cylindrical beam of which the section is a circle. Refraction, alone, under some circumstances, will bring about a like result. Thus, when double refraction takes place, as through a transparent plate of Iceland spar, of the two beams that emerge, one is thus altered, but the other is not. The former is said to be polarised, and a multitude of curious effects follow, which we have here nothing to do with. Light, reflected from glass, at an angle of 56°, or from water at 52° 45′, becomes polarised, and such rays of polarised light will not pass through certain substances which are quite transparent to ordinary light, so that the nature of these rays is considerably modified, and their properties are changed.

The polarising angle of air is a little above 45°. Thus, those rays from the sun that impinge on the air at this angle, are altered and flattened, while the others remain as before. Near the sun's place, and opposite to the sun, the polarisation is at a minimum, and in every part of a great circle 90° from the sun, it should be at a maximum. The light, therefore, that passes through a certain part of the atmosphere, and reaches the earth, is all more or less polarised, and the result is not without importance in many ways. Those parts of the sky where the polarisation is not produced, are called neutral points. There are several such points, but one only is important. They do not exactly coincide with the anti-solar points, (the positions they would theoretically assume) in consequence of the effect of refraction. The most important of them is 25° to 30° above the anti-solar point. Another is 18½° above the anti-solar point.

Without entering into any technical explanation of these curious conditions of the atmosphere in its action on light, it must be evident that they cannot exist without exercising much influence on the nature of the rays that reach the lower part of the air, and are reflected back from the earth. It is not easy to acquire a due notion of the value of changes of this kind, for we can hardly even guess at the extent to which they act, in reference to life in all its forms. We can only allude to them, and point out to the reader that there is still abundant room for discovery and speculation in this, as in so many departments of physical science.

The conditions of the upper part of the atmosphere have been made known of late years with great accuracy in the latitudes of England, by ascents effected in balloons. It has been found possible to reach, in this way, a height of more than six miles above the earth (more than the highest peak of the Himalayans), and this being effected in a country far removed from lofty mountains, the results possess great value, at least so far as the condition, over a district so exceptional as England, can be regarded as normal. The temperature, at the highest elevation reached, was—27° C., (—16⅗ F.) and the pressure of the air enormously reduced. The temperature was found to diminish, at first, at the rate of 1° C. (1.8° F.) for every 60 yards of ascent, but gradually the space required to lower the thermometer one degree became increased, till it reached, at length, 600 yards. A law of diminution may perhaps, hereafter, be discovered to range further into space, but it is, at any rate, certain that a great absence of heat must characterise the inter-planetary spaces.

A great and important change was also observed, during these balloon ascents, in the appearance of the prismatic spectrum in the upper part of the atmosphere. By means of the spectroscope, an instrument specially contrived for that purpose, the number of dark lines in the spectrum was found to be much greater at high elevations than near the earth's surface, the number of lines increasing to such an extent that they could not be counted. It would seem that these lines, or dark spaces, must be much more clearly marked, and therefore more indicative of the origin of light, in the absence of the atmosphere, than their appearance in the interrupted state in which the rays reach the earth would lead us to suppose.

CHAPTER XIII.

WINDS AND STORMS.

LIVING as we do at the bottom of an aerial ocean, which, if unmixed with aqueous vapour, would be about equally transparent to heat and light, our atmosphere, it may be thought, should be little affected by the direct action of the sun's rays as they pass through it on their way to the earth and water at the bottom of this great expanse. But it is owing to the transparency to heat, or diathermic condition of dry air, that the ordinary motions of the air—the winds and storms—are derived. Wherever the rays fall, whether the surface be land or water, some portion of light and heat is intercepted. The proportion is different, according to the angle at which the rays fall and the nature of the surface; but some warming effect must follow. If the rays fall vertically, or nearly so, a large portion enters and produces heat. If they strike at a great angle the larger proportion will be reflected. If the material be solid earth, it absorbs heat rapidly and largely. If water or ice, it produces less effect. Thus, the greatest effect will be produced on land, and within the tropics—the smallest on the ocean and near the poles. Within the temperate zones the heat received is very sensible, but towards the poles it is only in summer, when the sun continues to shine for several hours together, that the temperature is high, while during the long nights of winter the earth is never warmed at all; and thus the different parts of the land on the earth's surface are very differently heated. But the air, in contact with heated earth, soon acquires some of the heat and becomes expanded. In that case, it rises at once to the higher and lighter part of the atmosphere, while heavier air presses in to take its place. And thus both vertical and horizontal currents are excited. The water of the ocean also becomes heated, especially in warm climates, and this warm water is driven across the ocean by marine currents. It is thus always in circulation, and both land and water are constantly affecting the air over the whole surface of the earth. The air itself is kept in incessant motion, and long-continued calms, or districts where there is no motion in the lower part of the air for a long time together, are local and exceptional. When they do occur, they are not unfrequently precursors of some great storm, or accompanied by violent disturbances at some distant point.

An incessant circulation of the atmosphere is kept up by the action of the sun upon the earth. In a general way this may be described as a hot current rising from the equatorial regions, moving towards the north and south poles in the higher part of the atmosphere, and returning as a cold current from the poles towards the equator. If the earth were motionless and the surface heated regularly, these two currents would run directly north and south; but the earth, as we know, rotates on its axis from west to east once in twenty-four hours; and thus the air at the equator moves with the earth at the rate of about a thousand miles per hour.

A current of hot air rising from the equator and moving towards the north pole, to fill up the vacuum caused by the rushing in of the colder and heavier wind coming from the north, has a double motive force. It begins as a south wind, moving toward the pole, but it also moves with the earth; and as each particle of the earth's surface at the equator moves at the rate of a thousand miles per hour, so each part of the atmosphere has the same motion. But as this current advances northwards, moving laterally at the rate just mentioned, it reaches at each instant parts of the earth's surface moving less rapidly. This is evident, since every point at the earth's surface, from the equator to the pole, revolves in 24 hours, but the circle of revolution gradually diminishes from 24,000 miles at the equator to zero at the poles. The result is, that the current of air in motion will move in a spiral directed to the east, and be in every part a south-west wind rather than a south wind. So, the wind coming from the north pole toward the equator as a north wind, will find the earth as it advances moving more and more rapidly to the east, and will appear to be a north-east wind. It is evident, that what has here been said of the winds blowing on the north side of the equator, is equally applicable to those on the south side. In the latter case, the upper current will be a north-west and the lower current a south-east wind. It is the lower current which the inhabitants of the surface of the earth have chiefly to consider, for it has acquired a sufficient height in temperate latitudes to overtop all but the highest mountains.

We are made aware of the presence of the upper current, however, in various ways, independently of theory. It has frequently carried the light powdery scoriæ, or "dust" of volcanoes to a distance of more than a thousand miles, in a direction opposite to that of permanent under currents. In some cases, large and heavy fragments of erupted rock have been drifted while passing through the air, and have fallen at a great distance from their starting point. Upper currents are also recognised by the movements of clouds, which are often seen to cross the direction of the lower strata of the atmosphere. Lastly, balloon ascents have yielded abundant proof of the presence of air currents at various elevations, quite independent of each other, having very different temperature, and moving with apparent steadiness in some fixed direction.

The stream of air which rises high within the tropics, and there commences its course towards the poles, gradually becomes chilled and heavier, and descends lower and lower as it advances. At the Peak of Teneriffe the two currents may both be felt. The lower current coming towards the equator from the pole blows steadily on the sea, and for some distance up the mountain: but near the top the upper and contrary current is strongly felt. It has already descended thus far, and at length it approaches the earth. The land of Europe is greatly affected by this current. Thus we feel in our part of the world the influence of the hot moist air, lifted up from the Gulf of Mexico, instead of receiving the hot dry winds from Africa, as we should do, were it not for the advanced position of the wind, as already explained. The winds that come to us from any direction have been diverted from their original course many points of the compass before they reach our shores.

We have spoken of the north-east and south-east winds produced within a certain distance on either side of the equator by the combined action of the sun's rays and the earth's rotation. These winds are called the *trade winds,* as being of extreme importance to commerce. They have long been familiar to navigators, and are among the most steady and permanent winds on the earth. They are, however, by no means always equally strong, nor can they be depended on towards the limits of the zone in which they generally blow.

Beyond the limits of the trade winds, and between them, are regions of calms and uncertain winds. The northern belt is in a latitude about 30° N., and is called by sailors the *horse latitudes*. The barometer is said to stand higher here than at a distance, either to the north or south; but the belt is narrow and changeable. Beyond it, to the north, are the south-west passage winds.

The southern trade-wind region is much larger than the northern, in the Atlantic Ocean. In this sea the south-east trades are fresher and blow stronger than the others, and often reach to the tenth or fifteenth parallel of north latitude; whereas the northern trade wind seldom gets south of the equator, and usually ranges from 9° to 29° N. latitude. The quantity of land within these limits of latitude is very large, being fully one-third of the whole circumference of the earth at that point. The south-east trade winds blow over a belt whose width of land is not more than one-ninth part of the earth's circumference. This great difference in the quantity of land accounts for this difference in the force of these winds, and also in the quantity of aqueous vapour they carry.

The trade winds, in certain localities, become greatly modified. Thus, in inter-tropical India north-east winds prevail from November to March, and south-west winds from April to October. During the summer, the vast arid plains of central Asia, Tartary, Thibet, and Mongolia, have become heated, and the winds are turned aside and converted during summer and early autumn into the south-west monsoons. During the rest of the year they are cooled rapidly by radiation. The monsoons, therefore, are due entirely to local causes.

The currents of air once established, the south-west monsoon comes in from the Indian Ocean and the Sea of Arabia, loaded with moisture, and meeting the Ghauts (a coast-range of India surrounding a large part of the peninsula) its winds precipitate so much rain as to make particular localities in this district the wettest known spots on the earth. As much as from twelve to fifteen inches of rain sometimes fall in one day on the western slopes of these hills. The whole of the west coast of India is thus subject to periodical rains. Deprived of part of their moisture, these winds continue their course to the Himalaya mountains as moderately dry winds; but in crossing the range they become exposed to so low a temperature, and are lifted into regions where the pressure is so much reduced, that they deposit much snow, and become very much drier. They then pass on over the great plains, containing so little moisture as rarely to form a cloud. They once more become warmed, and ascend to the upper air to form counter-currents to those whose course has been already traced.

The monsoons differ from the trade winds in being periodical and not perennial. They occur, not only in the Indian Ocean, but also in the seas between Australia and China, and are always owing to the same cause. Similar periodical winds, also called monsoons, occur on the coast of Mexico, blowing north-westwards along the coast from May to December, and south-eastwards from December to March. Others, again, occur on the Brazilian coast.

The monsoons occupy the place of the trades as regular winds in those portions of the ocean where they occur. Between the southern trades and this tract of sea there are occasional calms, but these are often interrupted by winds which, when the sun is in the northern hemisphere, generally blow from some point between south-west and north-west, and during the rest of the year from south-east to north-east. These are sometimes called the north-west and north-east monsoons; but they are not monsoons in the usual sense of the word, as these periodical winds occur only north of the region in question.

The north-east monsoon extends a little south of the equator. It becomes regular near the coasts of Africa sooner than in the middle of the ocean, and near the equator sooner than off the shores of Arabia. It is most regular and powerful in the month of January in the northernmost angle of the Indian Ocean. It is not accompanied by rain on the Indian coast, like the south-west monsoon, but after blowing over a large extent of warm sea it becomes rainy on the east coast of Africa. The change from one monsoon to the other takes place gradually, but is generally accompanied by severe storms and tempests. When the wind ceases to blow from one direction on the earth the clouds in the upper part of the atmosphere may at once be observed taking an opposite course, but some weeks may intervene before the change is established at the surface.

With the exception of the parts of the sea subject to the monsoons, the trade winds are constant and steady, but they do not blow always and everywhere from the same quarter. They are in some places east winds, especially on the western side of the oceans they affect. They are also more to be depended on on the western than on the eastern side of an ocean, and are hardly sensible except on the open sea. They are generally stronger in the hemisphere in which the sun is not vertical, and are there also less easterly and more normal in their character. The weather is generally fine when the trade winds are blowing.

These winds are, as we have said, more distinct in the Atlantic than in the Pacific Ocean. In the former, also, they are wider and more powerful on the American side. In the Pacific they appear to be permanent only from about the meridian of the Galapagos islands to the Marquesas. The northern and southern boundaries of the trades within the temperate zone are generally marked by sudden changes of wind. Beyond this is a region of variable winds, which is more uniform in the Pacific than in the Atlantic, and more uniform in the southern than in the northern hemisphere.

The trade winds are confined to the ocean, but regular and constant east winds occur between the tropics. They are chiefly observed on level plains of great extent. Such winds blow over a great part of the Sahara, or desert of Africa, over the vast plains drained by the Amazons, in South America, and also on those in the lower part of the valley of the Orinoko. Other permanent winds are believed to affect the climates of Central Asia and Southern Africa. Others, again, greatly modify the condition of vegetation, and even of animal life, in Australia and the islands adjacent.

Storms are of various kinds. These are—(1). Disturbances of the atmosphere generally, in which case they are wind-storms. (2). Thunder-storms, or disturbances of the electrical conditions of the air, as effected by the passage of electricity of the ordinary kind from one cloud to another, or from a cloud to the earth:—these are thunder-storms. (3). Disturbances of the magnetic condition of the earth. The latter are sometimes called magnetic storms, and are manifested in the aurora (borealis or australis). Both electric and magnetic storms are of the nature of sudden shocks recovering an equilibrium of electric condition that had formerly existed, but had been disturbed. All are dependent on the electrical and magnetical conditions of the atmosphere and the earth.

Electric storms, although familiar and tolerably well understood, are very peculiar and remarkable phenomena. They are made evident to the senses by sudden gleams, or long sparks of electric light, called lightning, the latter kind being accompanied by loud crashing or reverberating noises in the air, called thunder. They are much more common and regular in certain parts of the world and certain districts than others. They are common in the tropics and in warm, temperate regions. They particularly affect mountain and hilly districts, they often pass up valleys, and they are more frequent during summer than in winter. In the colder temperate and polar countries they are comparatively rare. There are certain large districts where these storms are extremely rare.

Lightning is either forked or sheet lightning. It is believed that the former is the appearance when the electric discharge occurs within a few miles of the earth's surface, and is directly seen by the observer. When the discharge takes place below the horizon, or behind a dense cloud, only the scattered light reflected from the surfaces of the clouds illumined by the flash. reaches the observer's eye. This illumination of a portion of the heavens is called sheet lightning, and the distance of the discharge is generally too far to permit the accompanying thunder to be heard. It is even doubtful whether in all cases there be any noise produced, for sheet lightning may also be due to electric discharges taking place at very great elevations above the earth. It is well known that the discharge of an electric spark in extremely rarefied air is ill defined and wide, and the noise can hardly be propagated under such conditions. The cause of the peculiar brilliancy of forked lightning is to be found in the intense ignition of the particles of nitrogen and oxygen that form that part of the atmosphere lying in the path of the discharge. Such lightning is generally of a reddish tint, owing to the pink colour of the light emitted by incandescent nitrogen.

Thunder-storms are phenomena of extraordinary grandeur, and are sometimes very destructive, especially when trees or spires, or the lofty buildings in towns, are the media by which the electric force passes from the clouds to the earth. The extraordinary rapidity and intensity of the motion is sufficient to melt any metal through which it passes, and even to shatter or displace large blocks of stone. Any living being thus exposed is liable to immediate death, and the nervous system of the higher orders of animals is singularly disturbed. The state of the air is also greatly changed, and such change, though occasionally local, may extend for great distances in the atmosphere, and modify the weather for a considerable period. This, however, is exceptional, for in most cases thunder-storms, especially in summer weather and in warm countries, are eminently local, and are mere temporary and momentary re-establishments of the disturbed state of atmospheric electricity. In mountain countries it is not unusual to find them limited to particular valleys, and parts of valleys, neither travelling far in the valley, nor rising high on the slopes of the high mountains. From one of the hills in the valley of Switzerland, near Neuchâtel, (the Weissenstein) storms have been seen, accompanied by vivid flashes of lightning and by rolling thunder, passing along a thousand feet below the top of the hill, while the air above and around was undisturbed, and the sky overhead cloudless.

But this is not the case with magnetic storms on a large scale. They, also, are easily appreciated by the senses, for the auroral appearances that generally accompany them, though silent, are very striking. But there are other phenomena only recognised by instruments, although the results of such disturbances do not easily pass away. Almost all the great magnetic storms observed of late years have been accompanied by auroræ, and followed by severe and long-continued irregularities in the prevailing winds and weather over extremely large areas.

The usual mode in which great storms occur is by circular, or rather spiral, movements in the great body of the atmosphere, ranging over limited and often very small districts. A remarkable and very fatal example of one of these was the "Royal Charter" storm of 1859, so called because of the wreck of a large vessel of that name near the mouth of the Mersey. This storm commenced on the 25th October, 1859, shortly after a singular series of disturbances in the magnetic state of the earth. All over the world, not only in the Arctic but in the Antarctic regions, in Australia, South America, the West Indies, Bermuda, and elsewhere, auroræ and meteors had been unusually prevalent.* The currents along the meridional lines of telegraphic wire, both in the air and submarine, were everywhere disturbed. Many days before the storm, an extraordinary clearness of the atmosphere had been noticed in the north of Ireland, and the mountains of Scotland had never been seen so prominently. The preceding summer had been exceedingly dry and hot, and this weather had continued late into the autumn; but a few days before the 25th October the thermometer had fallen, and was very low in most parts of the country. There were northerly winds in some places, a good deal of snow, and very low barometers. The lowest barometer and a corresponding central lull, with light, variable winds, or dead calm, with rain, prevailed over areas of from ten to twenty miles across successively. At the same time there were violent winds around these spaces. From the middle of such spaces, at a distance of from 20 to 50 miles, the wind attained a velocity reaching from 60 to 100 miles an hour, and seemed to cross England in a succession of spiral eddyings towards the NE., the wind blowing from all points consecutively round the lull. Thus, while at Anglesea, the storm came from the NNE., in the Irish Channel it was northerly, on the east of Ireland NW., in the Straits of Dover SW., and on the east coast of England E. All these were directions at the same instant.

Thus there was an apparent circulation, or cyclonic commotion, passing northward, from 25th to 27th October, being two complete days from the first appearance of the storm in the Channel, while outside this current the wind became less and less violent. Even so near as the west coast of Ireland there were only moderate breezes.

---

* On the evening of the 25th, at about 7·15 P.M., there was seen at Holyhead "a bright ball of fire, which rapidly diffused itself, and illumined the dense mass of vapour, then filling the sky to such an extent that objects for a considerable distance around became visible as by day." On the same day and hour, about 12 miles west of Athlone, the sky being free from cloud, a meteor was seen in the direction of the Pleiades. "At first it was about the size of a star of the first magnitude—it advanced quickly towards me for four or five seconds, rapidly increasing in size—the colour was an intense white, like the electric spark. At the end of the four or five seconds the colour changed to bright ruby red, changing its direction and losing velocity. The red colour lasted one and a half to two seconds. It then burst into fifteen or sixteen bright emerald green particles, which disappeared after another two seconds." Many other meteors were described, but none so completely.

"As it is the NW. half (from NE. to SW., true) which seems to be principally influenced by the cold, dry, heavy, and positively electrified polar current, and the SE. half of the cyclone that apparently shows the effect of tropical air (warm, moist, light and negatively, or less sensibly electrified), the places over which one half of a cyclone passes are affected differently from others over which the other part of the very same atmospheric eddy passes, the sweep itself being caused by the meeting of very extensive bodies of atmosphere, moving in nearly, but not exactly, opposite directions, one of which gradually overpowers or combines with the other.

"On the polar side of a cyclone, continually supplied from that side, the sensible effects are chilling, drying up and clearing the air, with a rising barometer and falling thermometer, while on the tropical (or equatorial) side, overpowering quantities of warm moist air, rushing from comparatively inexhaustible supplies, push towards the NE. as long as their impetus lasts, and are successively chilled, dried, and intermingled with the conflicting polar currents.*

Many such cyclones, or special storms, have been recorded, most frequently in the tropics, but often on our own shores. They are always accompanied by similar indications, and generally of very limited extent. When they sweep over land they sometimes clear a straight path through thick forests. Something of this happened in the neighbourhood of Bristol not many years ago.

---

* "The Weather Book." By Admiral Fitzroy, p. 300.

CHAPTER XIV.

DEW, CLOUDS AND RAIN.

The atmosphere is never free from aqueous vapour. It absorbs it as water absorbs sugar and salt. The quantity it is capable of taking up varies with its density and temperature, but the quantity it actually contains in a given district depends greatly on the geographical position of the district, and on the course of the marine currents on the nearest adjacent coasts. Necessarily the air is more loaded with moisture when it has blown over warm water than when it has crossed a large extent of dry land, or lofty mountains piercing the higher and colder regions of the air. All the phenomena of aqueous vapour as a part of the atmosphere are extremely important and interesting, and the history of its condensation in dew, fog, mist, cloud, rain, snow and hail involves a vast multitude of facts, essential to a knowledge of physical geography.

Aqueous vapour is a powerful radiant of heat, and does not permit heat to pass readily through it. This we have already explained. It is diffused through air of which the mass is generally more than a hundred times greater, and before its temperature can be lowered sufficiently to be condensed, not only its own heat but that of the surrounding air must all be reduced. Solids near the earth's surface cool very rapidly by radiation into space through clear air, and thus objects on or near the earth may easily become sufficiently cold to cause the condensation of the vapour close to them, and even produce hoar frost, although, only a few feet above, the vapour remains uncondensed, and the air is not sensibly much colder than before. Such a deposit occurring, during clear, calm nights, on various objects near or upon the earth in the open air, is called dew. The more rapid and complete the cooling of the solid, the more heavy is the deposit. The cause of this phenomenon was originally explained by Dr. Wells, a physician, who, about half a century ago, was the first to give a definite and satisfactory account of it, basing his conclusions on numerous simple and ingenious experiments. It is essentially the result of the chilling, by radiation into space, of various bodies radiating heat very differently. Thus dew is deposited copiously on grass and painted wood, when none whatever can be found on gravel walks adjoining. Plates of metal, good conductors of heat, remain quite dry, while wood, a very bad conductor, becomes quite wet. Many curious and interesting results follow from a clear understanding of the subject of radiation, and the consequent different rates of cooling of various substances. Many of the effects attributed to the moon are due to the effect of radiation in the clear sky which accompanies a bright moonlight night. Putrescence is advanced in this way by the deposit of moisture on decaying animal or vegetable matter. Tender plants are nipped by frost, even when the air in the garden appears to have remained above the freezing point. In these cases the smallest screen—even a cobweb, would check the radiation and preserve the plant. A thin mat, or a tissue, however slight, is amply sufficient to preserve delicate vegetation from injury.

It has been proved by experiment by means of thermometers exposed on long grass during a clear night, compared with others at various short distances above the grass, that the chilling effect of radiation diminishes with extraordinary rapidity. Thus, at between 2 and 3 inches above the grass the chilling is only one-half; at a little more than 6 inches, one quarter; at a foot, one eighth; and at 6 feet, only one twentieth of the amount observed on the grass itself. It has also been proved that the difference of temperature between any radiating solid and the surrounding air is nearly constant, at all seasons and under all circumstances.

Notwithstanding this, there is sometimes a difference of as much as 18° F. between the temperature as shown by a thermometer placed on the grass and another thermometer hung a few feet above the grass. The grass is first chilled by radiation about 4° below the surrounding air, but the air in contact with this chilled grass is soon reduced to the same temperature. The tendency to keep always the same difference now acts to reduce the grass still lower, and this again cools the surrounding air yet more. This goes on till the temperature of the stratum of air near the grass is reduced very far below that which seems to belong to the grass itself. In this way it is that ice is sometimes formed during clear, calm nights, even in the tropics, when the temperature of the air is very high, and when, under no other natural conditions, can freezing take place.

But aqueous vapour is not only condensed from the air, when, on clear nights, the radiation of heat from solids in contact with the air is shown by a deposit of dew. It is far more frequently rendered visible as mist, fog, or cloud, and thrown down in comparatively large quantities as rain.

It is not difficult to understand the cause of these appearances. The winds and currents of air that are constantly in circulation are, for the most part, differently charged with moisture. A warm wind coming from the sea is loaded with moisture—a hot wind crossing a continent is dry. Even a very cold wind crossing water or ice takes up a sensible supply, which is for the most part retained near the earth's surface, for the upper currents of air being less dense than the lower, are less capable of holding up the vapour atmosphere. It must also be remembered that all land greatly above the level of the sea is colder than the lower lands, and, therefore, chills the air that impinges upon it.

Thus, then, when the heated air in contact with or near the water at the equator, or in the tropics, rises into the higher part of the atmosphere and gives place to the colder current coming in from the north or south, the direct result of the change is to place the hot moist air in a position where it has a tendency to condense some of the aqueous vapour carried with it. Such vapours form into mist or fog if chilled near the surface of the earth or sea. If, however, the change takes place high in the air, or if the earth be warm, and opposing currents of air exist at different temperatures and different levels, clouds will form within certain limits of distance from the earth, and, being formed, will drift away according to the winds that prevail at that elevation.

We may describe clouds, generally, as visible vapour suspended in the air at some distance above the earth. Possessing the shifting, formless, shadowy character of vapour, becoming visible or remaining invisible according to minute changes of temperature in different parts of the great aerial ocean, they combine distinct outlines with peculiar and striking colours and other characteristics, enabling us to speak of them as definite objects, with a capacity for change that is almost unlimited.

Clouds carry water from the ocean to the mountain-tops, they signal the occasions on which the electric forces balance themselves, they cause important modifications of light and heat on the earth, they are connected with the production of frost, they add to the picturesque effects which the landscape painter and the admirer of nature love to study, and they offer to the poet innumerable suggestions and similitudes.

The formation of cloud may always take place at the shifting contact of cold with warm currents at all heights in our atmosphere. There will be the same result wherever there are mountains or lofty plains, for these not being so rapidly affected as the air by change of temperature, and receiving much heat from the sun during the day, which they lose at night, are almost always of a temperature different from that of the currents of air which strike upon them. When rain has recently fallen, it is often curious in mountain countries to watch the incessant and rapid formation of cloud over some small wooded patch of land, the moisture from the warm earth steaming into the chilled air and being immediately converted into mist, which gradually accumulates till it breaks away and drifts to a distance, assuming a distinct cloud nature. It is equally curious to observe a narrow side valley in a mountain district covered for hours together with mist and rolling cloud, while the larger and more open valley into which it opens has a perfectly clear sky. The cause of this is, however, obvious. The lateral valley, enjoying less of the sun's cheering and warming rays, is colder than the more open valley adjacent; the air as it passes is therefore sucked up the side valley, and, coming into the cooler temperature of its sides, is at once condensed into mist and rendered visible. Such mist may turn afterwards into cloud.

In temperate climates, whether with or without mountains, clouds are formed at all elevations up to fifteen or twenty thousand feet, or even more; but those below ten thousand feet are more massive and more influenced by local causes than the others. The observations of Professor Piazzi Smyth at Teneriffe are exceedingly interesting on this head, as he was enabled, while living at the great elevation of 10,500 feet on the slopes of that isolated mountain, to recognise and record a multitude of curious facts. A cloud-bank was observed to extend widely at an elevation of 4,500 feet, at which height a NE. wind constantly prevailed, drifting the clouds towards the SW. At a far greater elevation (nearly 15,000 feet), a SW. wind was constantly drifting other clouds towards the NE.; and thus there were two systems of visible vapour in the air, the one travelling in a direction exactly opposite to the other.

The way in which water is taken up and held by the air in fogs and mists, or conveyed along in the form of a visible cloud, seems at first to involve mechanical difficulties. We will return to this subject when we have considered a little further the peculiarities of clouds and cloud motion. All we need now point out is, that the quantity of vapour existing in air in the invisible form depends on local temperature, and is probably at no time uniform over any considerable area, and certainly never the same for twelve hours together in the same place. It is found that when the temperature is 50° F., each cubic yard of dry air (about 168 gallons) can hold nearly 150 grains (one-third part of a fluid ounce) of water; at 32° F., or the freezing point of water, only one-half this quantity is contained; and at 70° F., nearly double can be absorbed and retained in an invisible form. A comparatively small change of temperature will thus at any time greatly alter the capacity of air for holding vapour in an invisible form.

It is not difficult to understand whence the vapour is derived that passes into the air. The great ocean covering three-fourths of the surface of our globe, the lakes and rivers present at frequent intervals on the land, the numerous smaller pieces of water, and the large tracts of moist earth protected from dryness by vegetation and constantly receiving rain,—all these insure a rapid supply whenever an increase of temperature requires it. The transmission from one part of the atmosphere to another is as rapid and complete as if no air were present and the vapour passed at once into empty space. In large unwatered tracts of country the atmosphere presents a very different appearance from that to which we are accustomed, but air, however dry, always retains some water, the actual quantity depending partly on the temperature.

When a change of temperature occurs, and the alteration is in the direction of increased heat, the air continues to absorb;

but the moment that a diminution of heat takes place, owing to any cause, not only does the power to absorb cease, but the power to retain is lost; and visible vapour represents the difference. Such vapour has a tendency, not unfrequently, to assume the form of the object by which it is caused. Thus, where mountains are present, a cloud seems to fix itself at the summit or on the sides of the mountain, at a certain level, and there obstinately remain. No matter how violently the wind may be blowing, the cloud is immoveable. Such a phenomenon is well known on the Table Mountain at the Cape of Good Hope. A similar appearance may be frequently observed on the more detached mountain-peaks of Switzerland, of which Mount Pilate (*Mons pileatus*, the cloud-capped mountain) is an excellent example. In these cases, it is not that the wind is unable to detach the cloud, but simply that the warm wind loaded with moisture is chilled and becomes visible, the chill commencing a short distance to windward of the object, and continuing at a distance to the leeward of it, until the air is no longer affected by the cool surface it has been in contact with for a time. If we take the trouble to climb the mountain and enter the cloud, we find it to consist of a driving mist, raw and chilly to the feelings, but of no great density. A change in the direction of the wind, bringing air not so warm, will immediately produce a clearing of the sky with a sensation of increased warmth; but any other change produces little if any alteration. In this case a permanent cloud is apparently formed and retained, although the cloud is really not the same for two seconds together.

It often happens in mountain districts, if the observer is situated at a high level, that he may watch beneath his feet the growth of a cloud, as it commences with steamy vapours from a patch of forest, and rapidly drifts away with some current of air. The same thing when seen from below is less easily understood, but it is very frequent.

When a cloud is once formed, it has a tendency to remain floating, suspended in air of about the same density as itself. In the higher regions of the atmosphere, where the clouds are chiefly formed at the meeting of two currents of different water capacity, sets of small or apparently small clouds are produced, all nearly of the same form, as all are due to precisely the same cause. Thus, we have the mare's-tail and mackerel skies, and other kinds, where numerous light fleecy clouds appear at a great elevation. In the technical language of meteorologists these are called *cirrus* clouds, from the peculiar curl they often present. It has been supposed that such clouds are composed of particles of snow. They occur in systems; long ranks of them extending in one direction for vast distances far above our heads, and being occasionally crossed by other systems, at other but also extreme altitudes. They present very varied and singular appearances. They are probably never less than three miles from the earth, and sometimes certainly much more. Their colour generally is the purest white, contrasting finely with the rich full blue of a clear sky. They have a tendency, derived from their mode of origin, to arrange themselves in parallel bands; and, by a well-known law of perspective, these appear to converge to points near the horizon. At the equator, the direction of the bands of such clouds was observed by Humboldt to be nearly north and south, but with us they run more frequently north-west and south-east Amongst these singular and exquisitely beautiful clouds are formed halos and mock suns, and indeed careful observation would seem to show that they are almost always accompanied by iridescence, though often very faint. It has been suggested that these cirrus clouds are the heads of columns of vapour rising from the earth, and precipitated as soon as they attain a certain elevation. If this be so, the visible cloud forms the capital of an invisible pillar of saturated air.

When these clouds are more dense, occurring at somewhat lower levels, and accumulating in larger quantity, but still retaining their banded appearance, they pass into another kind, called *cirro-stratus*, which resemble loose masses of carded cotton, and often pass rapidly into rain-cloud. Cirrus clouds are often seen near the horizon at sunset and sunrise; but it is on a fine summer's evening, when these loftiest vapours become tinted with the rich warm glow of the setting sun, that they are most beautiful.

The clouds called *cumulus* differ from those just described in many essential characteristics. They appear to be formed near the earth, and ascend gradually during the day. Thus, in summer, the sun will rise in a clear sky, or through hazy strata of cirrus and cirro-stratus, which immediately disappear. Towards eight o'clock in the morning, small flocky clouds are seen, which gradually increase in number and volume during the heat of the day, and then disappear towards sunset. On the mountains, one may see such clouds at one's feet in the morning; at noon they form a mist around us; in the afternoon they are far overhead; and towards night they have vanished. As the earth becomes heated, the air immediately above it is warmed, and absorbs moisture. This warm and damp but light air, rising to replace the cold and heavy air above, is soon chilled, and its moisture becomes visible. Towards evening, the ascending currents are replaced by descending currents, and the clouds disappear, being re-absorbed.

Such clouds are not often picturesque, but they not unfrequently present very grotesque and varied forms, changing with the most marvellous rapidity, and melting away in a singular manner. When of large dimensions, they cover the heavens and altogether obscure the sun, being in this state entirely without form and beauty; but whenever they are broken up, even the heaviest clouds are capable of presenting wonderful variety, and the most exquisite softness of pencilling. Like the cirrus, the cumulus is frequently in layers or strata, and is then called *cumulo-stratus*.

The true rain-cloud (*nimbus* of meteorologists) is limited to a moderate distance from the earth, probably not extending to more than four or five thousand feet. Being so near the earth, it is often seen to be drifted along, torn by the wind, and presenting sweeping and jagged forms, changing at every instant. The clouds are not in reality blown about by the wind as they appear to be, for they form part of the wind itself, the sweeping rain and the driving wind rising and lulling together. It is also well known, that while, to any one within a rain-cloud in the act of discharging, it appears that the cloud itself is in violent and rapid motion, the same cloud will appear, to a spectator from a distance, to be in perfect repose—not moving from the spot where, for some local reason, the shower occurs.

Many beautiful and familiar appearances are due to the rain-clouds. They pass with rapidity across and below other clouds, partially concealing and modifying them—often, by their peculiar gray tint, setting off the colours and intense whiteness of the more massive-looking *cumulus*, and the delicate fringes and curls of *cirrus* far overhead. Of all clouds, they are the most transparent; resembling sometimes drifted smoke or haze, and sometimes the most delicate curtain of gray air.

But they are also not unfrequently opaque and heavy, distinctly announcing their object. They are "wet, transparent, formless, full of motion, felt rather by their shadows on the hills than by their presence in the sky, becoming dark only through increased depth of space, most transluscent when most sombre, and light only through increased buoyancy of motion, letting the blue through their interstices, and the sunlight through their chasms." These clouds are admirable studies for the artist, as well as strikingly adapted to excite the imagination of the true lover of nature.

In their ordinary occurrence, accumulating gradually till they cover the whole vault above us, they may seem unmeaning; but when we are enabled to study them in the course of a storm, they are marvellously beautiful and picturesque. We will make use of an extract from one of Mr. Ruskin's works as fitly concluding our notice of rain-clouds. After describing the quiet masses of white cloud, gradually accumulating as the day advances, Mr. Ruskin tells us to "wait a little till we see those mists gather themselves into white towers, and stand like fortresses, piled every instant higher and higher into the sky, and casting longer shadows athwart the rocks. Out of the pale blue of the horizon, we may then see, forming and advancing, a troop of narrow, dark, pointed vapours, which will cover the sky, inch by inch, with their gray network, and take the light off the landscape with an eclipse which will stop the singing of the birds and the motion of the leaves together. Soon we may recognise horizontal bars of black shadow forming under them, and lurid wreaths creating themselves, we know not how, along the shoulders of the hills. And then comes the sudden rush of the awakened wind, and those watch-towers of vapour are swept away from their foundations, and the waving curtains of opaque rain are let down to the valleys, swinging from the burdened clouds in black bending fringes, or pacing in pale columns along the surface. As the sun sinks, the storm drifts for an instant from off the hills, leaving their broad sides smoking and loaded with snow-white, torn, steam-like rags of capricious vapour,—now gone, now gathered again; and the sun, like a red-hot ball, plunges through the rushing wind and rolling cloud with headlong fall, dyeing all the air about it with blood."*

---

* "Modern Painters," vol. i. pp. 259, 260.

The motions of clouds are curious, and involve an apparent difficulty, only to be understood by considering their origin. Masses of cloud are often seen to advance in direct opposition to the winds that blow near the earth, and these masses steadily make their way across the visible hemisphere either in bands, or, more frequently, in lens-shaped groups; not unfrequently the advancing end is more rounded or quite bluff. Such clouds put on strange and fanciful forms, changing rapidly, and imitative of any object the imagination suggests. At the same time, perhaps, a bank of white mist serves as a permanent background, curls of white fleecy vapour are in the zenith quite undisturbed, and shadows fall unexpectedly and inexplicably upon the landscape. Such a complication generally accompanies or announces rainy and windy weather, and is due to the existence of very distinct opposing currents of air at various altitudes, each striving for the mastery. A distant *cirro-stratus*, or fog-bank of the upper sky (the *stratus* is the name given to formal stratified clouds limited to no particular height), thus remains altogether unchanged in form or proportions for a long time, while a nearer cloud of similar form partly conceals and is entirely shadowed by it. At the great elevation of the upper cloud, at least three miles above the earth, the air is no doubt in steady motion; but whether the bank of cloud moves, or is still, its motion is not recognised at the distance of the observer. At half that elevation the same amount of motion of air and cloud is far more easily noticed, and even without any other difference, the lower clouds will then appear to pass along in front of the upper. As they pass along, the upper and lower edges of the larger clouds are constantly overlapping and interfered with by the currents of air above and below, and the cloud assumes a blunted truncated form, its bluff extremity pushing forwards into space.

While in many cases a cloud actually formed is driven onwards with the wind to its destined goal, in others, as we have already intimated, the whole cloud-phenomenon consists in a continuous reduction to the visible form of the vapour present in the air, either when the air strikes against the surface of a mountain, or meets with a different current and becomes chilled. In such cases the cloud is permanent, and varies little in shape or dimensions, while the wind may vary exceedingly in force, and may even change its direction without the cloud being altered. It is a well-known intimation of storm when huge rain-clouds, black with moisture ready to be deposited, roll on with increasing vehemence in a direction opposed to that of the wind, becoming heaped and piled, till the storm bursts, electrical explosions marking the recovery of disturbed equilibrium, and the rain falling in torrents. Such storms it is generally said "*clear the air*," and render it more healthy for animal life. They certainly produce a marked effect on its electrical state.

The colours and shadows of clouds are not less varied and beautiful than their forms. When the sun is near the horizon, and its light shines through a considerable thickness of vapour, the colour transmitted is always red, an excess of the yellow and blue rays being absorbed. Close to the western horizon, however, when the sun is about to set, and the clouds are not too thickly congregated, we find also every conceivable variety of yellow, passing from the palest and purest tint to the deepest and richest admixtures of yellow with red. Blue is a colour rarely found in clouds:—never by itself as a pure colour, and rarely in mixture either with yellow as any shade of green, or with red as in shades of violet and purple. The latter is, indeed, the most frequent of such admixtures; but it is generally to be accounted for without our being actually obliged to admit it as a positive tint belonging to the cloud itself. Green clouds and a green tint of the sky are not, however, extremely rare.

It seems strange, that as water is heavier than air, clouds should not only form but remain floating, and that in many cases they should lose the power of wetting which belongs to ordinary mists near the earth's surface. Certainly clouds neither float as boats on the air; nor are they retained only for a short time, like feathers, by friction and resistance; nor do the particles of water in a cloud consist of hollow spheres with void cavities, or with their interior filled up with light gas. No explanation of this kind is sufficient or satisfactory. Neither is the water-cloud like the cloud of incense, that rises and for a time floats in air while disseminating its fragrance.

To account for the permanence of clouds we must remind the reader of the nature of the vapour atmosphere. It is in its very nature an independent atmosphere. The shell of air that encloses our earth consists of several parts which have strict relations, and a certain dependence on each other, but at the same time are essentially separate, having undergone no chemical combination. Gases are in some important respects very unlike liquids, and this is nowhere more clearly shown than in the mode in which they mix with each other. Thus, if some of the light street gas, which is the substance used to render our balloons buoyant, were placed in a vessel inverted over another vessel in which was a quantity of heavy choke-damp (a gas often found at the bottom of old wells and pits, and so heavy that it may be lifted, and poured from one tumbler into another like water), then even if each vessel were carefully covered with bladder before the experiment commenced, the two gases would be found after a short time to have mingled completely, the lighter having descended through the two bladders to mix with the heavier, and the heavier having mounted to mix with the lighter. The vapour of water in the atmosphere is for all practical purposes a gas, and mixes as a gas with the other gases that make up the whole. It is, therefore, held up in the air just as the slightly heavier oxygen and much heavier carbonic acid are held up with and by the nitrogen. No doubt there remains much that we cannot fully understand in this mode of existence of mixed airs, and we cannot certainly be said to know why the heavier atoms of water remain permanently in contact with the lighter atoms of oxygen and nitrogen; but we may accept it for the present as a fact, hoping in time to recognise the cause and the mode of action of the law. At any rate there is no need to assume that the water is present in an unusual state, or that it is in any other than its most ordinary condition. As sugar or salt mixed with water becomes, as it were, fluid by being mingled with fluids, so the vapour of water behaves as a gas when mingled with air in our atmosphere.*

---

* The researches of Dr. Tyndall on the subject of heat radiating through atmospheres containing more or less vapour, have clearly shown, that when the sun's rays of light and heat pass through perfectly dry atmospheric air no heat is lost, while through certain gases and steam no heat passes. Thus, in proportion as the air is damp, in that same proportion does it absorb more heat from the sun's rays, and, at the same time, becomes capable of holding more vapour. In the same way also does the earth part with the heat it already possesses, the more slowly in proportion as its steam atmosphere is more dense, while on the other hand it is under such circumstances less heated by the sun. The change necessarily taking place every hour as different parts of the earth and atmosphere are exposed to the sun's action, thus insures that

The nature and continual presence of an invisible atmosphere of water is thus accounted for, and it is only when we come to the resumption of the visible form without a necessary conversion into drops of water falling through the air, that there is an absence of clear explanation. When, however, it is remembered that the property we call weight belongs to all matter, and that, for anything we know, the ultimate atoms of all are of the same weight, the differences being due to density or closeness of packing of the atoms, it will be seen that there is no necessary reason why visible as well as invisible vapour should not be retained permanently in the air. The vapour may be set free without assuming the fluid form. However this may be, it has never yet been proved that clouds are not limited to air in motion; for, as we have seen, a cloud may appear in perfect repose, even when violent and shifting winds are all around, the cloud being a permanent result of the actual motion of the air.

The conversion into a mist or raining cloud of what may be called a dry cloud, consisting of visible vapour not adhering readily to solid objects which have about the same temperature, seems to be in all cases accompanied with electrical action. In meteorological observatories, where the electrical state of the air is recorded by instruments, this is sometimes seen in a very striking manner. A sudden shower, occurring without previous warning, will in an instant set all the electric instruments in full motion,—gold leaves and pith-balls vibrating to and fro, and sparks snapping, now faintly, now loudly, so long as the shower lasts. Occasionally, and without cloud, moisture is also rapidly deposited from air which to the senses is quite dry. At all times the production of drops of rain involves electrical disturbance; whereas there is no proof, and not much probability, that the mere change from invisible to visible vapour involves any interference with the ordinary state of electric equilibrium.

It is in the tropics that the phenomena of rain are presented in their most striking form. Near the equator, wherever the sun is vertical, the earth below is heated in the highest degree, and the air is calm. An ascending current takes place,

incessant change so strongly indicated by the clouds. It must not be forgotten, that each change of vapour-condition is accompanied by a disturbance of the electric equilibrium.

but the regular winds gradually die away. The air becomes damp and like a vapour bath—the sky assumes a whitish tint and is overcast—clouds appear, followed by sudden showers, and these by fierce storms, until at length floods of rain descend, inundating the earth. After the sun has passed, and ceased to be vertical, the rains diminish, the air becomes drier and clear, and the regular winds are again felt. The great tropical rains follow the course of the sun, the ascending current of hot air neutralises the horizontal trade wind, the vapours are carried rapidly upwards, and become condensed.

The quantity of rain thus falling is very large. In one place (Cherra Pungee) it is stated to amount to 592 inches, or nearly 50 feet, in the course of the year; but the average at the equator is considered not to exceed 100 inches. This falls in about eighty days, the rest of the year being dry. In some localities the quantity of rain falling in single showers is very excessive. Thus at Cayenne 21 inches have been known to fall in a single day. Guiana, Brazil, and the western coast range of India, are places where the largest rain-falls are believed to occur, and in these places from 225 to 300 inches cannot be considered an unusual fall in a single year.

Receding from the tropics the rains become less periodical, and far less in quantity; but they are often distributed over a larger number of days. These are caused by the meeting and crossing of currents of wind from various quarters, some warm and moist, others cold and dry. Condensation then takes places, sometimes very rapidly. Near the western seaboard of the Atlantic, and on the shores of the Mediterranean, there are often spring and autumnal rains. At other places there are heavy rains at the time of the solstice. The mean rain-fall in the north temperate zone, though it varies much, does not often exceed 40 inches. The exceptional cases are in such localities as Wales, and still more remarkably the Cumberland mountains. The rain in these places is almost as great as in some parts of the tropics, and the showers that fall are also almost tropical. In the year 1862 there fell 182½ inches of rain at Seathwaite, in Cumberland, and less than 20 inches at Bishopswearmouth, in Durham.

Taking the rain-fall of the British islands as likely to be the most familiar example to the English reader, we may with advantage describe briefly the chief phenomena these presented, and proceed to compare them with others. The mean annual rain-fall of the whole United Kingdom we may assume to be something less than 34 inches, and this is nearly the same as that of Ireland. On the other hand, if England is estimated alone,* its rain-fall is under 30 inches, and that of Scotland (excluding Mull) is more than 33 inches. Thus already we perceive a great difference, and the broken insular form, smaller width, and more mountainous character of Scotland, are seen to produce a much larger deposit from the air than is the case with England, while the more direct exposure of Ireland to the south and west produces an excess in that country. When we examine either country in detail we find that geographical peculiarities explain the state of the case. Thus in England; at Seathwaite, in Cumberland, and at Coniston, in Lancashire, on the west or seaward side of the low, but important mountain chains of these districts, the rain-fall, as we have already said, is almost tropical. At Seathwaite it averages 127 inches, and at Coniston 71½ inches. So in Scotland, in the Isle of Mull, the amount is 74½ inches. On the other hand, at various places on the east of England the average does not exceed 20 inches, in Dublin it is under 22 inches, and at Edinburgh under 25 inches. Generally the difference between the west and east coasts, between the south coast and the interior of the country, between hill and mountain stations and those in plains, and between those places where the south and west winds first impinge on lofty ground and those where they travel over plains and valleys, is exceedingly marked.

Thus, near Bodmin, in Cornwall, on Dartmoor, the fall is 43½ inches; and at Helstone, in the same county, on lower ground, though nearer the coast, only 36¼ inches. At Waterford, on the south coast of Ireland, it is 39½ inches; at Sligo, on the west coast 38½ inches; and, as we have already said, only 21¾ inches at Dublin. At Liverpool, which is flat, it is 24¼ inches; and on the Lancashire moors adjacent 45 inches.

---

* In this average the exceptional localities of Seathwaite and Coniston are excluded. If included, they would bring up the amount of fall to 34 inches. They are, however, purely local phenomena. The averages are of ten years, from 1850 to 1859 inclusive, which, indeed, were 5 per cent. below the average of the last fifty years, but seem to correspond pretty well with the recent and present recorded statistics.

On the high ground in the West Riding of Yorkshire it is 50 inches; at Leeds, midway across England, 21 inches; and at Patrington, in the East Riding of Yorkshire, something under 21 inches. At Seathwaite we have already stated that the fall is 127 inches, and a few miles off, at Bishopwearmouth, in Durham, on the other side of the moors, it is only 17 inches.

It is sufficient to study any table of the amount of rain-fall in various localities in England to perceive the entire dependance of the average on local conditions. The air comes loaded with moisture from the Atlantic, and if it is met when in this state by a mountain side, it is chilled, and heavy rain falls almost incessantly. If it passes over a plain, or up a wide valley towards hills in the interior, the fall on the coast is moderate, and in the interior of the country greater. If it reaches the east side of the island without much interruption from hills it retains its vapour, but this rarely happens. Still the averages of the eastern counties of Sussex and Norfolk (26¾ inches each) are not far from the average of the central county of Leicester, 26⅛ inches, and higher than that of the south of Derbyshire, and parts of Shropshire, where only 24 inches fall.

The greatest quantity of rain in the British islands generally falls in the months of October and March—the smallest quantity in February. Rain falls on a very large number of days in comparison with the countries of continental Europe.

Bearing in mind these amounts of rain-fall in the British islands, it will be easy to understand that in the interior of continents the conditions must vary yet more considerably than with us, and that the apparently capricious and constantly changing fall is the result of causes familiar, and to some extent calculable. Beginning with the recognition of zones of constant precipitation, or frequent, if not constant rain, a little north of the equator, where the rain-fall averages about a quarter of an inch per day every day of the year, we find on the south of the line a district, having a rainy season of six months and a dry season of the same duration, over a great part of which rain rarely falls at night. The difference between these two tropical zones must be sought for in the general distribution of the land in the northern and southern hemisphere. While, however, the northern equatorial district is remarkable generally for almost constant precipitation, that part of it between the east coast of Africa and a line running from Japan to New Guinea, has rainy and dry seasons, and the rain-fall is there far heavier than elsewhere. The district includes a vast number of large and lofty islands, and the whole of the south and east coasts of Asia, besides the tropical part of eastern Africa. It is limited to the north by the vast mountain chain of the old world.

To the west and north of this district in the interior of Asia and Africa are vast regions in which little rain falls. These include the Sahara, or great desert of Africa, the deserts of Arabia and Persia, and the deserts of Beloochistan, Gobi, and Thibet. Five millions of square miles of land are included in this area. So, also, on the west of the great mountain chain of America, on the shores of Peru and on the northern part of Mexico, are districts of great length, though narrow breadth, where also rain is almost unknown. To the north and south of these tracts are others of enormous extent, including most part of the civilized world, where rain is unperiodic, but frequent. In these tracts there are indeed some portions almost dry, and some very subject to rain; some have wet and dry seasons. These depend on local position, and we may say, on the whole, and in a general way, that as we advance from a coast line to the interior of a continent or great island the rain-fall passes more or less gradually from a maximum to a minimum, and that in advancing from a cold to a warm climate the converse may be asserted, the rain-fall gradually becoming larger from the poles to the equator.

The amount of physical force exerted in the phenomena of evaporation and condensation of water by the agency of the atmosphere is one of those matters easily overlooked and very difficult to realise. The change in the state of aggregation that takes place when aqueous vapour is formed from the water of the ocean and carried into the air requires a development of force, compared with which all ordinary forces vanish. To convert a pound of water at the boiling point into a pound of steam at the same temperature nearly as much as a thousand times the quantity of heat or force is needed that would raise a pound of water one degree F. in temperature. But this latter force is equivalent to raising 772 pounds of water one foot high, and thus the conversion of one pound of boiling water into vapour is equivalent to raising 746,524 pounds weight (nearly 100,000 gallons of water) one foot high.

The total estimated rain-fall on the land of the earth, assuming the general averages for the tropics and temperate zones that are most accordant with observation, is not much less than 200 millions of millions of tons weight, and if to alter the above illustration we suppose this quantity annually removed from the sea by evaporation and deposited on the land, we shall find by a simple calculation that as much as 7,000 pounds weight of water are evaporated every minute on an average throughout the year from each square mile of ocean. The conversion of this into vapour, its conveyance through the air, and its re-condensation, involves an expenditure of force equivalent to the lifting of very much more than 1,500,000 millions of millions of pounds of water one foot high per minute of time during the whole period.

This vast and almost incredible result of the sun's action on the earth is altogether independent of, and in addition to, the force of gravitation; it is one of the results of that form of motion which we recognise under the name of heat, but which is certainly resolvable into the other forces of electricity and chemical action. It is a fraction only of the real amount of force exerted, for much of the water raised by evaporation from the ocean falls back again to the ocean without reaching the land, nor have we included the amount of force required to transport the vapour from one point to another. It is a work going on incessantly, and one that has probably been going on at nearly the same rate during all time. Were it not that the total amount of force exerted on matter is always the same, so that it is only the mode that has to be determined, not the force that has to be supplied, we might well believe that the force would be in time exhausted, and that not even the sun itself could endure a drain so vast and so perpetual.

Rain in all ordinary cases results from the complete condensation of aqueous vapour that has already become visible, either as mist or as cloud. But it is not absolutely necessary that these intermediate conditions should be passed through. An excessively fine rain sometimes falls in some countries in a clear sky during the fine season immediately after sunset. It is called *serein*, and is attributed to the cold resulting from radiation, producing immediate condensation. The elastic and transparent aqueous vapour itself, warmed during sunshine, begins to radiate heat when the sun disappears. The results are cold, condensation and rain.

We have already spoken approximatively of the quantity of water that falls on the land from the atmosphere. Its amount, as estimated from the observed averages of rain-fall in different parts of the world, may be stated as follows. The totals, though mere approximations, are not without value in reference to the uses made by nature of these large supplies, and the importance of local position.

	Area of land in square miles.	Total annual rain-fall in millions of cubic feet.	in millions of tons weight
North and south torrid zone	19,400,000	4,282,750,000	119,500,000
North temperate zone . .	25,150,000	2,160,500,000	60,000,000
South temperate zone . .	4,350,000	261,500,000	7,300,000
North and south frigid zone	2,600,000	70,250,000	2,000,000
	51,500,000	6,775,000,000	188,800,000

We have already had occasion—anticipating in some measure the results of the present chapter—to point out the mode in which this quantity of water is carried back to the parent ocean. A large proportion runs off directly in streams and rivers, a large part is re-evaporated, and the remainder disappears for a time in the interior of the earth to re-appear in springs. After working its way through the earth, this final residuum feeds the rivers with additional supplies.

CHAPTER XV.

CLIMATE AND WEATHER.

CLIMATE is a very complex matter, and one dependant on a great variety of conditions. It is the general resultant of all those atmospheric phenomena that we have been considering in the last two chapters, and it therefore includes the temperature of the air at various times and seasons, the range and variation of temperature, the direction and force of the winds that prevail, the liability to storm, the amount of humidity in the air at various seasons, the quantity of cloud, mist and rain, the distribution of rain, and the varieties of electrical condition. These, to some extent, affect and depend on each other, but all may ultimately be traced to certain general causes connected with physical geography. Among such causes are:—(1). The position of the station in latitude. (2). The size and figure of the land on which the station is situated, whether detached island, archipelago, or continent. (3). The elevation of the station above the sea. (4). The position of the land on which the station is placed, with reference to the neighbouring land. (5). The position, distance and direction, magnitude and elevation of the nearest continent. (6). The nature, magnitude and direction of the nearest great marine current to the shores.

Heat is a very essential part of climate. The absolute quantity of the sun's rays falling upon any level, unclouded spot on the earth's surface during the year would depend strictly on the latitude. Provided, then, there were no difference in the quantity of cloud, there would be none in the quantity of heat received in places on the land, provided the ground were level and the height above the sea the same. But though the heat falling on all such places might correspond, the quantity absorbed and available must depend on the clearness of the air and on the soil. Even when the conditions are most simple, therefore, places in the same latitude, and apparently under similar conditions, vary greatly, receiving and retaining different amounts of heat. But when it is considered how much heat is added or taken away by hot or cold winds, how completely some places are sheltered and others exposed, how warm are many sunny slopes, and how much many valleys lose of their fair proportion of sunshine,—how often valleys, plains and hill-tops are swept by cold winds, and are rapidly cooled before the heat of the sun has time to penetrate into the soil and rock beneath,—the inequalities of supply in different places under the same latitude will be seen to be infinite.

The quantity of heat received in any spot is expressed in figures by the average height of the thermometer during a whole year, estimated from observations made daily, and extending over many years. For this result it is necessary that observations should be first taken to determine the times of day at which the thermometer is nearest the average of the twenty-four hours. This being done carefully, the height of the thermometer is recorded with unfailing regularity at the same time, and when a sufficient number of records have been kept, the average is struck. Thus, at Greenwich, the average or mean temperature of every day in the year has been determined from observations ranging over a period of half a century, and from them it appears that the mean annual temperature is 48·8° F., this representing, therefore, the absolute heat. Other places in Europe, in the same latitude, have a different, and generally smaller, mean annual temperature; for the situation of England is favourable, and its climate warmer than that of many towns much further south in the interior of the continent of Europe. A line drawn through all those places in Europe whose mean temperature is 49°, would range a little south of Greenwich and would deflect very considerably to the south in crossing Europe towards Asia. Such a line is technically called an *isothermal line*, or line of equal heat, and marks one point in the estimate of climate.

To make up this mean annual temperature, however, we have some months of cold and some of heat. In England, at Greenwich, the average temperature of January is about 36½°, and of July nearly 62°, the other months being intermediate.

So, again, the average temperature of the day in January varies from 35½° on the 9th (the coldest day), to 38⅓° on the 27th, which, on the average of years, is the warmest. The mean temperature of the days in July is less varied, changing only from 61½° at the beginning to 62½° towards the end; but the averages are made up in each case of a number of different amounts.

Then, again, it is warmer in the day when the sun is shining than at night during his absence, and this difference is often considerable. The highest and lowest temperatures of each twenty-four hours being recorded, the difference between them shows the range of the thermometer for the day. This, also, is subject to averages; and thus we have an average daily, monthly, and annual range, as well as a mean annual range of temperature. All these require to be taken into consideration in determining and comparing climates.

It is by observations of this kind that we learn the mode in which the heat is distributed, a matter that affects climate to an extreme degree. The mere quantity of heat actually received during the year on the earth at any place is unimportant in its influence on life, compared with the mode in which the distribution is effected; so that one must judge of climate much more by the range of the thermometer than by its average height. It would appear to be an established fact that, *cæteris paribus*, more illness and death occurs when the mean daily temperature in England sinks below 45°, or rises above 65°, than at other times; and there is not a doubt that a wide thermometer range greatly increases the mortality, and modifies all tabular statements of sanitary condition.

The range of temperature may be estimated either in respect to years, seasons, months, or days. The difference is very great between winter and summer, and each month has its own peculiarities, but the daily range of the thermometer marks better the effect of temperature on health and vegetation than any other single fact.

The daily range is the extreme difference between the greatest heat of day and the greatest cold of night, and the average must be obtained from a series of observations extended over many years. There are no means of generalising in the science of meteorology without abundant facts, and the facts are of no value unless the instruments used are of the best manufacture, and have, previous to use, been carefully compared with known standards.

The average daily range of the thermometer at Greenwich is rather more than 16° F. In the month of December, however, the range is little more than half that amount, while during the months from May to September inclusive, it is very much more than the mean, averaging then as much as 20°. In other parts of the country, especially in the south-west of England, both the average and the extremes are much smaller.

That the reader, unaccustomed to consider this statistical way of stating the fact, may see more clearly the meaning and value of the difference of climate produced by a different range of daily temperature, let us present one or two familiar examples in illustration. In London and the country around it is not unusual, when we rise in the morning and look at the thermometer, in the month of June or September, to find it little above 40°, and sometimes it may not exceed 35°. If we have a register thermometer to refer to we may find, (or the state of our garden produce may show, in the absence of such an instrument), that there has been frost during the night. As the day advances the sun shines warmly, and towards two o'clock the heat becomes considerable, the thermometer rising perhaps to 70°. Towards sunset the heat diminishes rapidly; at night, if the sky is clear, there will be rapid radiation from the earth, the cold will become severe, and the thermometer will fall till it reaches the freezing point. There is thus, in the twenty-four hours, a range of 38°.

It may, however, happen that after such a day as we have described, clouds will cover the sky at night. Under these circumstances radiation ceases, and the night temperature will not fall below, if it even touch, 44°. The next morning, the clouds continuing, and the air being calm, the whole day may pass without the thermometer rising to 50°. During this day, then, the range will only be 6° instead of 38°, the average of the two days being 22°, made up in the way just alluded to.

These thermometer differences, though perfectly correct, do not agree in all cases with the evidence of the senses. When the sky is covered and there is a certain amount of moisture in the air, with a high thermometer, there is often a sense of chill, while with a clear sky and dry atmosphere, but a low thermometer, there is no feeling of cold, unless the wind blows from some cold quarter.

But temperature, though very important in its influence on climate, is by no means the only element for consideration. The barometer, also, records its facts concerning the pressure of the air, and various instruments are employed to register the direction and force of prevailing winds.

The pressure of the air is as constantly altering under the influence of changing temperature and wind as the pressure of the water on the rise and fall of the tide, and the amount of difference is more considerable, more easily detected, and much more important in its influence on animals and plants. For the air is exceedingly elastic, very easily affected by every cause of change, and, in return, a change in its condition at once affects all living nature. Just as there are tides in the sea, so there are tidal movements in the air,—waves of air passing along over our heads. Sometimes we are buried under heavy pressure, and the barometer rises to show it; sometimes we are under the hollow of the wave, the pressure is for a time greatly diminished, and the barometer rises to an unusual height. The air above us, being very elastic, adapts itself instantaneously to all these changes, and healthy persons, being almost equally adaptable, do not perceive them except by the aid of instruments; but when out of health, or when advancing years remind us that the elasticity of youth is gone, we become far more sensitive, and require no barometer to inform us of the vicinity of east or south-west winds, and the altered pressure consequent upon their advance towards us.

The position of any place with regard to other land, the elevation of the adjacent land, and the vicinity of a great ocean, are the local peculiarities that chiefly influence the character of prevailing winds. Thus, in England, the land extends towards the east, north-east, and south; high land lies far away towards the south-east, cold land exists towards the north-east, a warm ocean lies to the west, and huge masses of ice occasionally float down in that ocean from the north to certain limits of latitude. It is not, therefore, surprising that east winds are dry, north-east winds generally dry and cold in spring, south-west winds warm and wet, north-west winds cold and wet in spring, and pleasant in summer and autumn, and south winds hot. It would be strange if it were otherwise. On the other hand, at New York the contrary conditions prevail: east there corresponds with west here, west corresponds with our east; north-east wind there comes over the ice floating down from the North Pole, while south-west winds come across the dry, hot plains west of the Mississippi. So with other localities: each has its own set of winds; some are dry and burning, some moist and warm, some cold (whether wet or dry); and in all cases for a similar reason, namely, that the wind blowing across a large tract of the earth's surface gradually acquires certain characteristics from the state of the surface.

If, then, we would describe a climate, we cannot do so without alluding to the nature and peculiarities of the prevailing winds. To say that north-east winds prevail in the east of England during a certain season, is to characterise that season as either hot or cold, according as the period of the year is summer or winter. The east winds of spring are cold, and generally dry, because they pass over much land, giving out moisture rather than absorbing it. The east winds of summer are often hot and dry, because at that period Europe is far hotter than England. The south-west winds are almost always warm, and wet or dry according to the temperature of the land; for hot air absorbs much more moisture than cold, and therefore a wind fully saturated with water, coming within the influence of cold earth, deposits rain in large quantities; while the same wind, if blowing over land heated above its own temperature, becomes relatively dry, being ready to absorb moisture, and affecting animals and plants accordingly.

Bearing in mind these remarks, the importance of position as influencing climate will be recognised. There is, however, another point; for, near the extreme edge of a continent, and in all the islands situated near the border-land of a continent and a great ocean, there is inevitably a great contest of opposing winds. On the west coast of Europe, where England is situated, there is a frequent meeting of wet westerly winds with dry easterly winds. Throughout the year the former change but little in temperature, because the ocean generally, and the currents of that part of the Atlantic that wash the English shores especially, retain an average temperature. But the east winds are much more changeable, for in summer they are often intensely hot, and in winter equally cold. During the former season, heated by the earth, they are displaced by the cooler west winds coming from the sea; during the latter, the warmer westerly breezes are displaced by the cold east winds. The great seat of these changes is the fringe of land near the ocean, and the islands adjacent. Here the storm-winds blow; on these shores the battle rages; and at the critical periods between the seasons, in the months of March and April in the early year, and of September and October in the later, the result is seen in the so-called equinoctial gales, for which these parts of the year are so unfavourably notorious.

Nor is this the only result of the opposing winds. Whenever warm and moist air comes in contact with other air colder and not extremely dry, the mixed air is unable to retain the whole of the moisture in an invisible form, and the water contained becomes visible in fog and mist, if it does not fall in rain. Thus, the shores of England, on the south coast especially, are enveloped in fog during, or at the commencement of, the east winds of spring and autumn; and even in summer a sudden change of wind will often be exhibited in this very disagreeable form.

The quantity of rain falling when the clouds, formed at the contact of winds of different temperature, are unable longer to retain the water they have absorbed, has already been stated. Ireland, from its position, and Westmoreland, Cumberland, and Wales, from their high land, are the most remarkable districts, in this respect, in our part of the world. In the tropics, where, owing to the much higher temperature of the earth and air, the quantity of water carried up into, and held in solution by, the air is enormously greater than in Europe, the rains are proportionally heavier. Climate is greatly influenced not only by the rain-fall, but by the proportion of cloud in the atmosphere; and not only by the amount of rain, but by the number of days during the year on which it falls, the amount of rain that falls at a time, and the mode of its distribution.

The general conditions of the climate of England are not very unfavourable in these respects, and notwithstanding the prevalent impression among foreigners, that the sun never shines in England, it is probably not far from the truth to say, that there are few countries where each day of the year contains so fair a share of weather on which it is safe and pleasant to be exposed to the air as our own island. Owing to the conditions already alluded to, the number of days partially clouded is very large; so large indeed, that one can hardly say that it is much less than three hundred and sixty-five. But the quantity of cloud is rarely sufficient to hide the sky during the whole day, except during the equinoctial seasons. Generally there is a mixture of fair and cloudy weather every day; and though we do not often enjoy uninterrupted sunshine, we rarely suffer from long-continued unfavourable seasons. Rain seldom falls so heavily as to do mischief; and few parts of the country, except those near the level of the sea, suffer seriously from floods, even in extraordinary seasons.

In this respect, again, both animal and vegetable life are favourably influenced by our island climate. While in the interior of Europe the corn crops are sometimes much heavier, and the vine ripens its fruit in the open air, the cold of winter is often intense, and the summer heat scorching. On the other hand, the average temperature and frequent rain-fall on the western shores of the Continent, and especially in the islands there situated, insure a permanent clothing of vegetation, singularly pleasing to the eye, and by no means unprofitable to the farmer. The clouded state of the air also, while it keeps off heat and the radiation of heat from the ground, does not appear to be unfavourable to the growth and ripening of many very valuable crops; and the variety of these crops fully makes up for the increased certainty, but more limited range, of useful vegetable products in other countries. It is also well known, that almost all domesticated animals are most healthy, and admit of fullest development, in the comparatively moist and changeable but moderate climate of the coast, than in the more extreme temperatures and more regulated conditions of the interior of a large tract of land.

The electrical condition of the air is an element of climate, which, though not yet measured very satisfactorily, is too important to pass without notice. The condition of the air, recognised by meteorologists under the term *ozone*, has yet to be explained. According to Professor Tyndall, ozone may be a peculiar aggregation of oxygen atoms. Heat dissolves this union and causes the ozone to vanish. However this may be, the air is certainly subject to very singular and important electrical changes, marked and measured by the methods used to determine the presence and quantity of ozone in the atmosphere. During certain seasons, and in certain places, the air is well known to become highly unfavourable to human constitutions; or, in other words, it so acts on the human frame as to induce fever and other diseases, apparently without reference to mechanical impurities contained in it. Assuming that this is owing to some determinable state, and combining observations, it would seem clear that the miasmatic condition is generally accompanied by a peculiar want of development of ozone. This may be understood to mean that the air is then in an exceptional electrical state, within the power of observation to record.

In this, as in so many other matters, the vicinity of the ocean, and the constant freshening of the air by mixture with other air that has passed over a large extent of sea, seems favourable to life, while the influence of a large tract of land is unfavourable. Islands are, therefore, *cæteris paribus*, more healthy than places far removed from the sea, although there is no doubt that some islands, especially in the tropics, where the decay of organic matter is extremely rapid, are among the least healthy localities.

Electric storms can hardly be said to influence climate very much, although they are generally regarded as leaving the atmosphere in a more healthy state than before the storm. Hail, essentially an electric result, is occasionally produced in the air in all countries; hail-storms of moderate extent being chiefly common in the vicinity of the sea, while very severe hail-storms in temperate latitudes are more frequent in the interior of a continent.

So many matters combining to produce a certain kind of climate, it is clear that even in the same very small tract of land there may be differences in this respect. How great these differences are, and how many varieties may be found, even within a very short distance, can hardly, however, be understood without much careful inquiry. In England, the climate of Brighton and that of Torquay are well known to differ essentially. The climate of Bath is very different from that of Cheltenham; and Malvern, again, is different from both. All these are quite distinct from Harrogate, and Harrogate is different from Scarborough, while both are unlike the lake districts of Cumberland and Westmoreland. It would be difficult at present to say exactly why these differences exist; but the fact is notorious, and the full bearing of such a fact is extremely important.

The climate of Europe generally is more extreme than that of England, and that of England more so than that of Ireland. The outlying lands—those nearest the Atlantic, and those most completely detached—possess most nearly the climate of the ocean, and the lands far within the continent exhibit an exact contrast. Wet winds blow from the sea, and as they advance inland become drier, so that when they reach the opposite coast they are the driest that can be felt, unless there are large tracts in the interior covered with water. Cold winds blow from the Pole, but become hotter as they near equatorial land. Winds blowing over the lofty snow-covered Alps are always cold, and those coming across the sandy plains of Africa are always hot; but as they advance, they also become modified, and if they meet, they cannot fail to influence each other. On the other hand, winds blowing from the warm waters that cross the Atlantic from the Gulf of Mexico are first wet and hot, and only become cold and dry when they have crossed mountains and discharged in the shape of rain their excess of moisture. These inferences are so evident that they only require to be pointed out.

And it is evident that these simple principles, applied to other less-known lands than Europe, must be equally true, and must lead to just conclusions. When, on the east coast of Australia, north of Sydney, the west winds blow like a sirocco, with a temperature and force like that of the blast from the mouth of a vast furnace, what is this but an indication of the dryness and heat of the interior of that continent? That they only exhibit this peculiarity at certain seasons is equal proof that, at other times, the interior is neither so hot nor so dry.

Wherever, then, prevalent winds are characterised by certain peculiarities of condition, whether they be wet or dry, hot or cold, it is certain that they have been subjected to influences which are usually not difficult to comprehend. Climate is so affected by them that the direction of a mountain chain, scarcely visible in the horizon, the position of a large tract of distant lowland, the presence at special seasons of icebergs floating in a sea a thousand miles away, or the fact of a current of water crossing, by a marine current, some great ocean that washes the shores,—these are the simple elements from which the general climate of a country may be deduced; while the level of the land, the course of a river, the range of a few low hills, will any of them be sufficient to produce a local modification sufficient to alter the details of climate, and greatly affect health and vegetation.

And if, in the course of ages, a change should take place in any of these elements, by the alterations that are constantly being produced by great natural forces always at work on the earth, it is clear that the climate must undergo a corresponding modification. If, for example, by a convulsive movement, or by a series of small alterations of level, the Gulf stream should make its way through the Valley of the Mississippi to the great lakes of North America,—thus diverting a current of warm water that now crosses the Atlantic, and removing its great influence from European to American lands,—the result would be to diminish very considerably the average annual temperature of all parts of Europe, but chiefly to render the British Islands exceedingly less warm, and somewhat less wet, than they are at present. If, at the same time, the lands of northern Europe, and the bottom of the Polar Sea adjacent to them, were elevated, the ice that now stops short of Norway might reach permanently as low as Scotland, and parts of Europe might be in the condition of Greenland and Labrador. An alteration so considerable might, and certainly would, occur were the comparatively small, but very possible, changes we have indicated carried out; and the greater part of the plants and animals that now flourish must either find fitter place in warmer lands to which they could migrate, or be destroyed from the face of the earth. The latter result would seem inevitable if they were unable to adapt themselves to the new climate, and were prevented by natural obstacles from migrating to better positions.

On the other hand, if the Gulf stream, continuing to bring warm water, not only crossed the Atlantic, but was enabled, owing to a depression of the plains of Europe and northern Asia beneath the water-level, to pass across to the Pacific, or connect itself with the Mediterranean,—thus isolating Europe,—the temperature of the smaller lands thus left behind would be considerably higher and much more equable, and the climate very much moister; rain would be heavier and more frequent; cloud much more continuous; fog and mist incessant; and wind, perhaps, much less troublesome. In such a climate, as in Norfolk Island in the southern hemisphere, there would be little of the vegetation that we are now familiar with, but a rank and luxuriant growth of ferns and grasses would overrun everything. Even palms and tree-ferns might well flourish, and all marsh plants would multiply with extreme rapidity.

And all this marvellous alteration would be consistent with a very small increase of annual temperature. The winter would be very much warmer, and the summer a little cooler; the days would rarely be hot, and the nights never cold. Man might and would remain under such circumstances, as he can adapt himself to any climate; but most of the other animal inhabitants would be seriously affected, and many quite destroyed.

If the change were very gradual, some of these might, however, adapt themselves, and many would be replaced by other tribes brought in from a distance, so that no great revolution need take place to bring about a marked revision of the animal and vegetable inhabitants of an eighth part of the land on the globe, provided a moderate amount of alteration of level of the land were to take place within a period of a few centuries, or, at the most, in a few thousand years.

It may seem that we are assuming physical impossibilities to explain conditions that never did and never will occur. So little is this the case that changes, fully equal to those alluded to, may, perhaps, have taken place since man has been introduced upon the earth. Very much greater, but perfectly conceivable, changes are suggested to the geologist when he begins to study the mode in which the earth's crust has been formed, and would explain the phenomena presented to him by every heap of gravel, every quarry of limestone, and every pit of sand.

Changes of climate and changes of the earth's surface are simultaneous, and both have certainly been produced ever since the earth was subjected to those influences of air and water that seem to us essential to its very existence. It is as easy to imagine the air always perfectly still, or the waters of the ocean to continue without a ripple, as it is to suppose that the relative level of land and water has always been the same. If the air moves, the water is disturbed; if the waves beat on the shore, the coast line is modified; and if the land is altered, the climate is adapted to the change: all these movements being in harmony with each other, and all incessant and inherent in the very nature of things, as presented for human observation.

Climate is interesting, not merely in itself, as affecting our feelings and health, but in its relations to the wide and large sciences of physical geography and geology. It is not a question of latitude and longitude, for the south is not necessarily warm and the north cold; east wind does not always bring rheumatism; the south wind need not be hot, nor is the south-west always accompanied by rain. The climate also that now characterises any given place need not always have prevailed there. At another time it may have been much colder or much hotter in that place, without any alteration in the position of the earth's axis, without a different quantity of heat having radiated from the sun, and without assuming that heat was formerly communicated from the interior of the earth to the surface. These theoretical assumptions may have their interest, and may or may not be based on sound evidence; but the mere fact that the climate in the northern hemisphere was once warmer or colder than it is now, is not of itself evidence that ought to be adduced in proof of them. A study of climate, and the causes of climate, will remove many apparent difficulties that are presented to the young geologist, and will give a rational idea of certain conditions that every one ought clearly to understand.

But climate may and does change by the influence of man and cultivation. By the drainage of land and the removal of forests, as we shall see in a future chapter, the conditions of a country are so far altered with respect to its rain-fall, and the moisture of the air, that the temperature becomes permanently affected. It is estimated that in this way the mean annual temperature of England is 2° F. warmer than it was a century since; that the summer and winter temperature are both less extreme, and that the rain-fall is gradually but steadily diminishing.

This view is supported not only by general experience and by tradition, but by the comparison of a large number of actual recorded observations.

Weather is the condition of the climate of any particular country or district. It varies from day to day in most parts of the temperate zones. but in the tropics, and in some special, but limited areas, it is constant, and may be entirely depended on during the whole dry season.

Let us endeavour to bring together in a narrow compass some of the chief peculiarities of weather and its changes, accounting for them, as far as possible, by reasonable causes. We may thus, perhaps, obtain an insight into this somewhat obscure subject.

A fine day in a fine season is an event worth recording, and involves a goodly variety of conditions. On such a day we have a bright sun, but the sun's heat is not scorching, nor does its light produce a painful glare; the sky is clear, and the clouds, if any, are light and high, not streaky or in heavy, cumbrous masses during the day, and towards evening they clear away, leaving only a few that are rosy and pink at sunset. The colour of the sky is blue, but not too intense, and not extending quite to the horizon. Distant objects are visible, but not so sharply defined as to appear unusually near. The atmosphere is really heavy, as shown by a high state of the barometer; but to the feelings it is light and elastic. The air feels dry, but not harsh, containing water, but in a state capable of absorbing more than it contains. The temperature is seasonable, not far removed from the average temperature due to the time of year. There is motion in the air, but it is not enough to be called wind. It proceeds from a quarter generally favourable for fine weather in the place of observation. The electricity of the air is in a state of equilibrium. There is a fair supply of *ozone*, and there is no disturbance of the magnetic forces.

An average number of such days as these, occurring at intervals, separated by cloudy and rainy weather of no long duration, and not accompanied by violent and continued wind, electric or magnetic storm, or sudden and frequent changes in the temperature and pressure of the air, characterise a fine season; and several fine seasons following each other, produce a cycle or period of fine weather. A certain amount of electric storm and hail in summer, intervals of heavy rain, wind, and storm near the vernal and autumnal equinoxes, and an average of snow, frost, and magnetic storm in winter, are by no means incompatible with fine seasons. During such seasons the fruits of the earth ripen, and the ordinary crops of the country are obtained.

Bad weather and bad seasons are naturally the converse and opposite of fine. They also recur occasionally in cycles, and alternate with fine weather and fine seasons. It would be unnatural if this were not the case, for it is the result, inevitable as far as we know, of the laws governing our earth and system.

The general average of the weather for a country or a district represents, fairly enough, the climate of the district, and in this sense it may be said that hardly any two places a few miles apart have precisely the same climate. In a general sense, however, the climate of England is spoken of as one thing, that of France as another, and so on.

It is quite conceivable, and even probable, that the climate of a place may in the course of a comparatively short time undergo a change, although it takes a large number of observations to prove it. By removing the trees, draining the land, and altering the crops, a certain alteration of climate is necessarily induced, inasmuch as the average temperature and moisture become altered, and these are climatal essentials.

But though climate *may* change or be changed, we may almost assert it as an axiom, in most parts of the world, in temperate latitudes, that the weather *must* change. There are places where these changes are exceedingly small, but we may safely assert, in a general sense, that weather is changeable and climate uniform.

Climates, as we have seen, are different in different places; whereas the weather, though changeable in any one place, may be the same at the same time in many places. This has been ascertained by systematic observations, commencing by previous arrangement at the same instant at a number of stations in different parts of the world, and continued at equal intervals. Thus it was found that on the morning of the 3rd of February, 1842, rain was falling at the same time throughout nearly every part of the United States of America, from the Gulf of Mexico in the south to beyond Lake Superior in the north, and from beyond the Mississippi in the west to far out in the Atlantic in the east. Over an area of at least a million of square miles there was for hours identical weather; and there have been other instances recorded where the whole land of Northern Europe has been under the influence of rain-clouds at the same instant, and for some time.

The weather is often extremely different on the two sides of a mountain-chain, across a narrow channel occupied by water, or even in two localities on land a few miles distant from each other. It follows that while there are causes which influence weather of exceedingly wide operation, there are others altogether local, and one can readily believe that the indications also will be somewhat different. The prognostications and causes of change of weather must evidently be studied with reference to this important difference.

There is, however, a third condition of weather, when it is neither uniform over a wide tract nor variable within narrow limits, but when, as is the case of certain storms, it travels over land and sea at a nearly even pace, occupying and affecting a narrow belt, but within that belt producing effects indicating the exercise of enormous mechanical force. During the great circular storms, or *cyclones*, alluded to in a former chapter, the weather travels along in this manner, as a desolating hurricane surrounding a comparative lull. While the wind of the hurricane is blowing at the rate of sixty or eighty miles an hour, the whole storm moves on, generally from the south-west towards the north-east, at a rate not exceeding twenty miles an hour. The signs and causes of this travelling weather are somewhat different from those of the other two kinds.

The weather is essentially the state of the air at the place and time of observation, and change of weather involves the action of some external causes altering the condition of the atmosphere. But, as the reader will have seen by our account of a fine day, this involves a good deal. The actual weight of the air above our heads, "the pressure of the air," is constantly varying from a multitude of influences. The temperature of the air also changes every hour of the day. The moisture in the air varies with the temperature. The electrical state varies from many causes, and affects the others to a marked extent. The direction of the wind frequently changes, bringing new currents of air with altered temperature, and in a different electrical state. Each of these causes and results of change requires a special instrument to measure its amount, and each observation has to be regarded in its bearing on all the others.

There is thus a great complication of phenomena, and no one instrument alone is sufficient to record the elements of weather. We will consider presently the use and relative value of the various contrivances that have been invented, and are commonly used; but, before doing so, let us see how far we may become weather prophets without any instruments at all.

We may either trust to our own observations of the external world, or, which is better, combine these with notices of the habits and instincts of animals. In this way any one can, by care and attention, come to possess an almost instinctive perception of weather changes.

The state of the air is one of the first things that may be studied with advantage in reference to the weather. Those who live in the open country or in the neighbourhood of the sea can readily observe this by the appearance of objects near the horizon. In a large city it is more difficult, but even there some of the indications are obtained.

There is hardly a more certain prognostication of coming change than a peculiar sharpness and clearness in the outlines of distant objects, enabling us to see more of them and to see them more plainly than usual. This is often looked on by those who are not weather-wise as a proof of fine weather instead of change. There are times when the state of the air is such as to bring up above the line of the horizon the form of objects actually below it, thus producing mirage. Mirage, in hot, dry climates, is not necessarily followed by change; but in all parts of northern Europe, and generally in all temperate climates where rain falls irregularly, unusual clearness and irregular refraction are followed by bad weather within twenty-four hours, or, if continued for some days, severe storm is almost inevitably at hand.

The quantity, mode of arrangement, and form of clouds, are all matters greatly to be looked at if we would foretell the weather a little in advance. Very light, lofty clouds, ranging in lines, but detached from each other, and often crossing each other's directions, are frequently the first signs of change and coming wind after continued fine weather. These *cirrus* clouds are called by sailors *cats' tails*, and the sky covered with such clouds a "mackerel sky."

To these clouds, generally many thousand feet above the earth, belong the halos occasionally seen surrounding the sun and moon; and the appearance of such meteors is considered unfavourable.

In summer they announce rain, in winter, thaw.

By degrees the light clouds descend and become more prominent. They pass either into heaped masses of *cumulus* cloud, like carded cotton, or into dense horizontal *stratus* clouds, forming at sunset and disappearing at sunrise. Both kinds pass into grey, formless, leaden clouds, which gradually cover the whole face of the heavens, and at last empty themselves on the earth in rain.

A very sudden alteration of form, or shifting of the place of clouds, or a sudden obscuration of the sky without clouds in motion, is an indication of a state of the air generally belonging to changeable weather. When the round, heaped clouds appear early in the morning, they often gradually disappear as the day advances, and after noon the sky is clear; but when they come on after noon, and increase towards evening, obscuring the sunset, they generally terminate in rain. Any violent and rapid motion amongst the clouds, one group crossing another, owing to various currents of air at different altitudes, indicates the approach of changeable weather.

It has been determined by careful observations made during balloon ascents, and confirmed by what is noticed on high mountains, that at a height of a few thousand feet above the earth there is a stratum of air in which cloud is often present, above and below which the air is in a very different state. This stratum forms a kind of dividing plane, and the more immediate changes of weather no doubt commence there, while the more distant alterations require a longer time to perfect.

A fine sunset is a valuable indication of the weather of the succeeding day. It requires, however, some experience to appreciate the exact state of the clouds in this respect, and the probability of interference by changes of wind or temperature. Among signs of fine weather an early and heavy dew has often been noticed. It has also been observed that hail in summer is generally preceded by great heat, and followed by cool weather.

The state of the air in which smoke rises vertically and to a considerable height, is known to be frequently followed by fair weather, whilst the opposite state, in which the smoke is beaten down and refuses to rise, is unfavourable.

The direction of the wind, and the direction of the change when the wind veers round, are among the most valuable indications of weather open to the general observer. The quarter from which wind comes may be discovered by observing a streamer or weathercock, which is not affected by trees or buildings. With us in the British Islands, northerly winds, whether from the east or west of north, are generally cold, and southerly winds warm. North-easterly winds, in winter and spring, are cold and dry, but in summer often hot. North-westerly winds, in ordinary seasons, are fresh and pleasant in summer, but cold and wet near the equinox. South-westerly winds are generally warm and often wet.

Our chief gales proceed from the SW. or NW., but some that are also severe come from the NE. South-easterly winds are rare, but in summer generally warm.

Winds, proceeding from any easterly point, proceed over a large expanse of land, and those from the west, over water. The former are dry, and the latter charged with moisture; but it sometimes happens that a wind, after proceeding for a long time across land or water, is, for some reason, thrown back again in a contrary direction along the earth's surface. In this case the apparently dry west wind is really part of a wind that has come from the east, and the apparently damp easterly wind really came from the ocean.

But although the direction of the wind affords valuable information, as indicating generally the conditions to which that part of the air has been exposed for some time, the mode in which it changes its direction would seem to be far more important as a prognostication of weather. An account of this, however, belongs rather to the consideration of instrumental indications, as it involves a series of observations.

A large amount of weather news is obtained by watching the habits of animals and the conditions of vegetation. The former, especially, afford the readiest, and even the surest, proofs of coming change that are open to our observation. The flight of birds and insects, the departure of fishes from their usual haunts, the movements of cows and sheep in the fields, or of domestic animals in the house, are among the phenomena that will occur to every one; but they can only be made use of by those who are thoroughly familiar with, and minutely observe, nature. Many of us, indeed, have our own instincts in this respect; and there are cases within the sphere of general knowledge where human beings, our friends or ourselves, feel without seeing those changes of wind that precede or accompany changes of weather. Amongst human weather-indicators are the martyrs to rheumatism and neuralgia; those who have felt the racking pain from old and imperfectly-healed wounds; those from whom proceeds the dry, consumptive cough; or those who suffer from the bronchial irritation that no artificial atmosphere can soothe.

All these conditions of the air are the result of causes which, if clearly understood in their relative importance and mode of action, would be reducible to direct observation and calculation. They may be described in a few words as being dependent on the pressure of the air, the temperature of the air—not only at the surface, but at various heights—the dew-point or state of moisture of the air, the rain-fall, the clear or cloudy state of the upper air, the direction and force of the wind, the electrical state of the air, the presence or absence of *ozone*, and the magnetic condition of the earth and atmosphere. Instruments are in use by means of which all these matters can be determined. These instruments, to be of any value, must not only themselves be good and accurate, but they must be compared with some fixed standards. They must also be used systematically—either always and everywhere at the same hours of the day, or so frequently that the observation of the agreed times can be deduced by calculation.

The first and most important instrument of observation is the BAROMETER. It is a simple contrivance, consisting of a column of mercury placed in a long empty tube, open at one end and closed at the other. When inverted in a small cistern of mercury, the fluid metal descends from the top or closed end of the tube, leaving an absolute vacuum behind it, and it continues to descend until the weight of the mercury in the column exactly balances the whole weight of a column of air of the same size to the very top of our atmosphere. It is a mode of weighing this column of air, and it does so with perfect accuracy.

When properly made and compared with a standard, and not disturbed, it is almost impossible that a barometer of the usual kind should get out of order, and quite impossible that it should fail in recording correctly the facts we ought to expect from it.

The barometer tells us one thing only—namely, the pressure of the air at the moment of observation. This may seem to be a small matter; but in temperate climates, an alteration in the pressure of the air is, in fact, the most accurate indication of every important change that takes place in the atmosphere. In climates where the weather is little variable, the mercury in the barometer rises and falls in exact accordance with the sun's position above the horizon, so that, in the tropics, it might serve as a time-piece. In temperate climates, these minute though regular changes are masked by others, more considerable and less regular.

To be of any value as a weather-gauge, the barometer requires frequent and regular observation, and a comparison with observations concerning the temperature and the direction and force of the wind. In the normal state, or at the commencement of a series of observations, it should be compared with the determined mean height for the day and place of observation during a long period.

Assuming that we commence right, then if the mercury falls slightly but steadily for many hours, without other indication of change, bad weather will follow; and the longer it is delayed the worse it will be. If the fall is sudden and considerable, with a south-west wind, and the mercury rises again, squalls and gales of wind may be looked for from the south-west, but they may soon be succeeded by fine weather. If, while the mercury falls, the wind veers round from the south-west to south and south-east, severe storms will probably follow. If the fall is very inconsiderable, but the thermometer drops, and the wind changes from east to north, severe storms from the north-west will probably follow. In all these cases, by constantly watching the barometer, and comparing its movements with those of the thermometer and the wind, the nature of the coming bad weather can generally be determined. In north-easterly weather the barometer is usually high and the thermometer low, so that storms from this quarter are less clearly indicated than from others. The same is sometimes the case with north-westerly weather. In southerly weather, on the contrary, the barometer is very sensitive, and falls considerably.

The thermometer is of great value as a weather-indicator; but for this purpose the average temperature for the day at the place of observation must be known. A temperature continued for some time below or above the average, is an almost certain indication of change. In summer, electric storms follow unusual warmth; and in winter, gales of wind from NNW. or NE., are not unlikely to succeed a low thermometer and almost steady barometer.

The direction of the wind, and the agreement or disagreement of this direction with the average of many years at the same period or season, is an important observation. When the wind, in shifting, goes round in the direction of the hands of a clock, from north by east to south, or from south by west to north, the change may be looked on as not unfavourable; but when the wind "*backs*" and veers from north by way of west to south, and from south by way of the east towards north, bad weather may be expected to follow. Occasionally it happens that north-west winds are greatly in excess, and the result of this is likely to be unusual rain. Settled north-west wind brings cold and fine weather; but continued west and south-west winds are usually followed by rain. It has been observed, that a prevalence of westerly weather near the time of the equinox precedes a wet summer or winter.

The coruscations of the aurora, indicating magnetic storms in actual progress, are often followed in our latitudes by bad weather, especially when they occur in summer and autumn; but the precise relations of magnetic disturbance with weather-changes are not yet fully understood. Indications of those great storms, or hurricanes, which occasionally sweep over limited areas with irresistible force, are tolerably certain, and correspond so well with others that have been previously and since observed, that they may take rank amongst settled facts.

Peculiarities of weather, however great and strongly marked, must not, even when they extend over many years, be assumed to indicate permanent changes of climate. If we look back at former records of weather, we find that at all times years of favourable seasons have succeeded each other, until people begin to forget that the contrary may happen; and when the unfavourable time comes, we are by no means prepared to recognise it as a part of a well-marked series of events. There is no doubt that Pharoah's dream of the fat and lean kine is a prophecy that will last for all time, and although we may not be able to foretell the exact year of change, the general fact of periodicity of weather is clearly established. The time may come when, by a sufficient experience arising from long-recorded accurate observations, the evil day may be more nearly anticipated, and some of its most serious consequences evaded.

But such and so accurate a knowledge of the laws that govern the weather as to enable us to foretell what will happen some time in advance, is neither common nor easy of acquisition. A mere passing glance at the barometer, without reference to the state of the wind, the temperature, and the electrical state of the air, affords absolutely no intimation whatever, inasmuch as the barometer is valuable only in comparison with itself at a former time, and with facts recorded by other instruments. A prediction of the weather from mere atmospheric appearances carefully observed, is, on the whole, much more likely to be correct; but even this is valuable only as far as it brings to bear experience, reflection, and the exercise of common sense.

It will also appear that to judge of the weather a week in advance, by noticing the hour at which the moon becomes new or full, or by observing the weather at such hour, can only be a very vague and uncertain method, subject to various causes of local interference; even if any such law of lunar influence were based on accurate observation and long experience.

It is not that valuable suggestions may not be obtained by collecting rules based on these suppositions. All observations —and we may even say all modes of connecting observations so as to deduce laws general or local—have a certain value, as they may suggest the true explanation, even if they do not give it; but we wish to show how complicated the problem is, and how impossible it is that there should be any simple solution. When the weather-beaten sailor or the old shepherd shakes his head and prognosticates a coming change which seems to less experienced observers altogether unjustified by any appearances, but which turns out correct, he gives the result of a life-long observation of small signs, of the nature of many of which he is hardly aware himself, and which, in fact, combine all that a dozen instruments and as many careful meteorologists could discover. Exactly in proportion to the experience and habit of close observation of natural appearances is the value of such an opinion; and this is all that can be said for the meteorologist also; for he compares the experience of a large number of persons, and combines their results, before he is justified in expressing an opinion; and his conclusions must fail should he neglect some correction, which, however small, may largely influence the result.

The study of the weather leads to the consideration of some of the highest problems and most remarkable speculations of physical astronomy, and connects itself directly with investigations concerning light, heat, and the various forms of electrical action. Like all honest inquiries into natural phenomena, it commences with observation and experiment of a simple and homely kind. It requires that a large number of facts should be recorded; it carries its inquiries through many departments of knowledge, apparently little related to each other; and it lands the inquirer at last on a far higher level than he originally anticipated. He who sets himself to record weather and draw deductions from his observations, is no trifler, and his labour is not light. He must not only daily, at the same hour, record the result of his observations; he must make the necessary corrections, and bring his work into such a state as to compare it with what others have done elsewhere; he must himself make the comparison of his own with other observations, and with his own observations of former years; he must watch the course of vegetation and the habit of animals, and must notice carefully all the particulars of every meteoric appearance; he must, if living on an island, estimate the influence of winds and ocean currents, not only on his own shores, but a thousand miles away from his place of observation; he must estimate the influence of the mountains, plains, and valleys of the adjacent continent; he must inquire concerning the snow and frost on the remote and scarcely inhabited shores of the polar lands, and the ice set free from those lands, and floating on the broad ocean; he must ever be ready to accept and act upon the slightest hint thrown out by nature or by his fellow observer; he must hold his knowledge firmly, and his opinions, prejudices, and mere impressions, very loosely;—in a word, he must be patient and persevering, always ready to receive and record facts, and always cautious in deducing or admitting theories.

It is impossible to consider, even in a very slight degree, these phenomena of weather in their direct relation on the one hand to the sun and moon, and periodic changes in the constitution of these distant bodies, and on the other hand to ourselves, as representing the highest form of organisation with which we are acquainted, without being struck with the mutual dependence that exists between the material and immaterial parts of the great system of creation. Distance and time seem annihilated when we watch the action of these mighty and mysterious influences, and we may almost recognise the reality of an existence unhampered by material impediments, when we find an instantaneous response of our innermost senses and sensations to a material stimulus applied within the burning atmosphere of the sun. Who is there who has not felt the influence of climate and weather clearing up or obscuring his intellectual faculties? We attribute this, perhaps correctly, to an indirect action through the state of our health; but who can say how much of it may not be due to some direct action hitherto unknown, proceeding from the great source of motion and force in our system? It would not be wise—nor, indeed, is it safe to carry speculation far in such a matter; but, perhaps, some of those peculiarities of constitution that have puzzled and distressed many persons of high nervous organisation, really owe their origin to a more ready sensibility to real but indefinable natural forces.

We have been drawn away in some measure from the immediate subject of the weather in these last remarks; but before concluding, we have a word to say to those who believe that "the former days were better than these"—supposing that because there are a few unfavourable seasons our climate has changed, and will not again be what it was in their youth.

The tendency of all observation on climate is to show that it is subject to a number of periodic changes; and we are fully justified in believing, not only that the periods are many, but that we are by no means acquainted with all. There is, indeed, no known exception to the periodicity of everything connected with our system; and while a few years will probably suffice to reproduce some phenomena, others may not recur for many centuries, or even thousands of years.

On the other hand, it is equally certain that no absolute uniformity of weather ever did or can exist in a temperate climate. The climate remains, but the weather changes. This, after all, is only in accordance with the great system of nature, which involves throughout the most perfect order and method, but in which we may recognise the elaboration of order and uniformity out of an amount of varied detail practically unlimited.

PART THE FIFTH.

FIRE.

CHAPTER XVI.

VOLCANOES AND VOLCANIC PHENOMENA.

In certain parts of the earth, amongst the great mountain chains, or within a moderate distance of them, and generally not very far from the ocean, there are conical hills, rising sometimes into lofty mountain peaks, remarkable not only for their regular form, but for a cup-like depression at their summit, and still more remarkable as being composed either of loose scoriæ, or of couleés of rock that has been poured out from the bowels of the earth in a state of igneous fluidity. Such hills or mountains are sometimes grouped and sometimes far distant from one another. They are of all heights, some certainly existing much below the level of the sea, and some at least 28,000 feet above the sea. But their essential features are the same everywhere. They offer a singular contrast to all other hills or mountain masses in their regularity of form, and in the rocks of which they are composed. They are evidently due to some action going on in the interior of the earth, and the ashes and molten rock of which they are formed sufficiently mark their origin to be igneous. They are VOLCANOES. They are not confined to our earth, for similar appearances have been recognised in, and are even exceedingly characteristic of the moon our satellite.

Few things in nature are more strikingly different from the ordinary appearances presented at the earth's surface than a volcanic district. Few things are more alarming to the senses, or more suggestive to the imagination, than even the most insignificant example of a volcanic eruption. It is difficult to avoid exaggerating the importance of phenomena that appeal so strongly to the senses. It is difficult to understand how such convulsions, when in their extreme of intensity, can avoid breaking up and destroying all the great landmarks of creation, and obliterating every appearance of simple mechanical action. We see that they must have been going on during a vast period of time, and we feel bound to attribute the accumulation and modification of all the great masses that make up the greater part of the earth's crust to causes that are connected with these disturbances.

But let us look at the subject from another point of view. A volcano is one of a limited and even small number of points on the surface, where there is communication with the heated interior. A crater is the gullet or depression in a volcanic cone, by which the heated matter from the interior has come to the surface, being lifted up by some expansive force. The heat in the interior must have been great enough to reduce or melt into a glass a large proportion of the materials common at the surface, and chemical forces must have been in active operation, decomposing, combining, and changing the ordinary materials of the earth's crust. Out of such a crater there will issue steam, various gases at a high temperature, ashes or fragments of all sizes, including broken films of glassy scoriæ that have coated bubbles of gas, and burst into a thousand atoms as they rise into the air. Very large rocks have been flung out from them to a distance of miles, as if from some huge piece of ordnance. At considerable intervals of time, and sometimes without notice, the steam, ashes, and rocks, thrown out from the crater have been accompanied by couleės of molten rock issuing like the slag from some great furnace, and this slowly advancing over the surface of the earth or the bottom of the sea, has spread itself out in films on the ground, or collected into fissures and cavities, affecting thus the physical features of the district in which the phenomenon has taken place. It is not too much to say that phenomena of this kind are at once terrible and influential in a high degree. But it is important to remember that they belong to the ordinary history of the earth. They are only exceptional in as far as they are confined to certain small districts, and within the districts they belong to they exhibit a certain regularity.

Nor are there a number of such points erupting at the same time in the same district. There are many volcanoes that have all the usual characteristics of burning mountains, but from which no eruption has taken place within the history of the human race. There are others of which we know that they have done terrible mischief, but now they are apparently exhausted. Others have only recently erupted, after an interval of unknown duration. Some, again, are constantly indicating a modified activity, while some act at intervals, but with intense energy.

There is no doubt that some of the great volcanoes and craters of the earth are magnificent and terrible objects. Of all of them the crater of Kilauea, in the island of Hawaii, (Owhyhee of Captain Cook) would seem to be among the most remarkable. This island may be compared with Sicily in size, but its volcanic phenomena are on a far grander scale. It is triangular in shape, the sides measuring respectively 100 miles, 88 miles, and 76 miles. It would seem to be entirely volcanic. It contains three lofty volcanic summits—Mount or (Mauna) Loa, the best known, being 13,760 feet, and the others nearly 14,000 feet, and about 10,000 feet respectively. As is the case in Mount Etna, the land slopes so gently to the volcanic cones, and these are so large, that their great altitude is not recognised. There are two craters on Mauna Loa, both active. The higher or summit crater measured, before the last eruption, 13,000 feet by 8,000 feet in its larger and smaller diameters, and was depressed 784 feet below the western side. Kilauea, the best known of them, is far the largest crater on our globe. There is no cone of ashes surrounding the crater as in Etna and Vesuvius. The traveller rises on the gentle slope of the dome to the edge of the pit and looks down a depth which, before the last eruption was about 1,000 feet, to a plain of bare rock, more than 2 miles in length—the bottom of a vast amphitheatre 7½ miles in circuit. Between the edge of the crater and the bottom is a wide terrace or ledge extending round the whole of the interior at a depth (in a normal state of tranquillity) of about 650 feet from the top and 340 feet from the bottom. The average slope of the dome, or central part of the mountain, is only 6° 30′ (less than Etna, which is 8°), and the diameter of the base of what must be called the cone, is more than 45 miles. The area of the base of the cone is, therefore, more than double that of the whole area covered by the lavas of Etna. The region of volcanic action is 70 miles in diameter. Indeed the whole island must be regarded as within the area.

The great pit crater of Kilauea is 16,000 feet in length, and has an average breadth of 7,500 feet. It includes an area of 4 square miles, an area sufficient for a city of a hundred thousand inhabitants. At one extremity there was some years ago a lake of boiling lava measuring 1,500 feet by 1,000 feet. This was the throat or gullet communicating with the interior. The rest of the floor was covered with a multitude of cones and craters, but is constantly changing. At one time the lava, which is remarkably fluid, rising rapidly, fills up the whole vast area of the crater to the height of many hundred feet above the bottom; but it rarely rises near the top, as an eruption usually takes place from some lower point on the side of the mountain, when the pressure has become sufficiently great.

Great eruptions took place at Kilauea in 1823, 1832, and 1840. Between the latter year and 1855 the whole central area of the floor was elevated 600 feet, the old ridge or platform being reduced to a pit 200 feet below the central platform. A gullet 200 feet in diameter at that time opened to the molten rock below instead of at the old lake. In 1855 a visitor counted 60 lakes of fused lava on this platform, and observed a countless number of cones. This was in the early part of the year, and in the October following there was a great eruption from the summit crater of Mauna Loa 20 miles distant. This crater was estimated to be 12,000 feet above the sea. The lava did not overflow the edge, but burst out about 10 miles below. This at least was the case with the principal stream, which soon reached 60 miles in length, with an average breadth of 3 miles, and a thickness of from 300 to 600 feet.

One of the points of chief interest in the last eruption in Hawaii is the fact, that there were no accompanying earthquakes or other disturbances, and no eruptions of ash. There is no record even of steam, nor does it seem likely that any great amount of steam can have issued without ejecting a certain proportion of ashes. The absence of ashes, and of the ordinary phenomena of an eruption, is a remarkable feature of the great volcanoes of the island.

A volcanic eruption on a large scale generally commences with subterranean noise, followed by dense volumes of smoke, consisting almost entirely of aqueous vapour. With the smoke and vapour are mixed up *lapillæ* or ashes, which have been already described as fragments of films, coating bubbles produced during the boiling up of the lava. These all together rise into the air to a great height (often some thousand feet), spreading out when not blown aside by the wind, and putting on the appearance of a vast palm tree. The material thus thrown into the air is so abundant and so light that it reaches into the upper currents of the atmosphere. It also continues to rise from the crater for so long a time that these currents have time to sift it, as it were, and distribute it in uniform beds, some of one size and some of another, over an area amounting to thousands of square miles. Thus at Coseguina, in the Andes, an eruption commenced on the morning of the 20th January, 1835. The cloud rose, and the ashes were distributed continuously for forty-eight hours. The fall was so light and so dispersed that not till after that time was the deposit thick over the surrounding country. The air remained darkened by the cloud of ashes for thirty-six hours after this. It was, indeed, so dark that men could not see each other, and the fowls went to roost. At the end of that time objects began again to be recognisable at a distance of 10 or 12 yards. In this state the air continued two days longer. Afterwards, for twelve days, the light was still partially obscured, and during all this time a fine impalpable dust was falling. All this happened at places 50 miles south of the volcano. The powder was conveyed in the direction of the under currents of wind to a distance of 700 miles, at the rate of 170 miles per day. That which reached the upper currents was distributed to a distance of 1,200 miles, in a direction contrary to that of the lower currents of wind. A ship at a distance of 1,100 miles from the volcano sailed 40 miles through floating pumice.

Accompanying, or rather succeeding the light dust, pumice and scoriæ are often ejected, and very large fragments of the walls of the crater are thrown into the air and fall at a great distance. It is on record that a mass of rock measuring 300 cubic feet (10 tons weight) was once projected 9 miles from the crater of Cotopaxi, also in the Andes. Smaller volcanic bombs are thrown in large quantities, and fragments of the crater wall, some tons in weight, can always be seen beyond the foot of the cone of Vesuvius for a long time after an eruption. So large has been the quantity of fine ash and scoriæ from Vesuvius that Pompeii and Herculaneum, two towns at the foot of the great cone, and some distance away, were overwhelmed during the great eruption of A.D. 79, and remained buried under them, lost to sight and knowledge for nearly twenty centuries. It is usually after these preliminary eruptions that there pours forth from fissures in the walls of the volcano, or from the broken edge of the crater, a flood of molten rock or lava. This is sometimes in such quantity as to cover up large tracts of country. Within ten weeks at least 40,000 millions of tons of fluid lava were ejected in Iceland in 1783 during a short eruption, and this mass was spread over a wide area, its thickness in many places not exceeding 10 feet, though in others amounting to 500 or 600 feet. The recent lavas of Mauna Loa, before alluded to, are on a far grander scale, and, as already observed, they flow out without the convulsive movements belonging to an eruption of Etna and Vesuvius.

Volcanoes are distributed over the earth in a manner which may be described as orderly and systematic. Upwards of four hundred principal cones, each involving a group of smaller cones, have been described. Many others exist, and most of the named groups occupy a large area, the whole of which is affected by volcanic influence. The cones themselves are in groups within a limited area, sometimes isolated, but more frequently in systematic arrangement along a definite axis. All those which we shall refer to at present have either been known to exhibit activity during the historic period, or are presumed to have done so upon good circumstantial evidence. In addition to the volcanoes believed to have been active in the historic period there are many doubtful cases, and many of which it may be said that indications of volcanic action, within a comparatively recent period, exist, although the evidence of recent activity is insufficient to justify us in ranking them as recent volcanoes.

In noticing the distribution of volcanoes it is well to recall attention to the fact already alluded to, that most of them occur in islands, or along a coast line near the sea. The exceptions to this general rule are extremely few. The following tabular view of the principal groups will be useful for reference, although the subsequent notices referring to them will not follow in the same order.

Position of Volcanoes.		Number of principal cones.
Atlantic Ocean.	Northern part	10
,,	Central part	10
,,	Southern part	3
Gulf of Mexico—West India Islands		10
Mediterranean—sea and coasts		5
Red Sea and African coast adjacent		2
Indian Ocean (west side)		3
Asiatic Continent		5
Asiatic coasts and islands.	Southern part	75
,,	Eastern part	110
Eastern Archipelago and Pacific Ocean		16
America.	Northern series	45
,,	Central series	45
,,	Southern series	54
Antarctic land		3

The actual number of volcanic vents in a given district is not of itself of much importance, for the indication that may seem to be suggested of greater volcanic activity where there are many cones is hardly borne out by the facts. The districts within which the number of volcanic craters that have erupted within the historic period is very large, are sometimes, though not always, those of inferior energy, while many where only a single group of cones is recorded, are among the most remarkable on the earth. Nor must it be assumed that all those mentioned in the list under different headings are not related to each other very directly. The list is given for the convenience of the reader in estimating the localities marked by volcanoes, and enabling him to detect those where no volcanic phenomena have been experienced.

Referring to former chapters, in which the position of the great enclosing lines of mountain chains and oceanic basins and sub-basins have been approximately traced (see chapters v. and vii. *passim*), the reader will soon be able to estimate the value of the facts there noticed, and their bearing on the important problem of the earth's early history. It would seem, that almost without exception, the volcanoes and volcanic bands are to be found running within the various basins or drainage areas into which the surface of the land is divided, but that in some cases different bands approach and interfere with or run into each other. Wherever three of these irregular basins meet in a point there are lofty table lands and mountain peaks. Wherever the edges of two come together in a line there is a ridge or mountain chain; and, generally, where one of the basins is oceanic, and the ridge approaches the sea, there is a line of volcanoes marking the contact. Where the great mountain chain does not everywhere approach the sea, as in the old continent, the volcanoes are grouped chiefly where the sea is at hand. It has sometimes been supposed that volcanoes are distributed partly in lines and partly in circular groups. There is every probability that the circular groups, which in almost every case consist of groups of islands in open ocean, are but the visible points of eruption of extended lines. None of the so-called circular groups are so large as some areas within known lines, and most of them are clearly traceable in their mutual relation. M. Mallet has remarked, that "nearly all the clusters or circular groups of volcanoes are situated in the ocean, and far from continental land; they stand on and are connected with each other by oceanic plateaux, rounded submarine ridges, shallows, rocks and islands, and by similar connexions with points of continental coasts, either mountainous or volcanic." *

The great volcanic lines may be described in a general way as ranging along the edges of the great oceanic basins. The most active is that of Java and Sumatra, separating the China Sea from the Indian Ocean. That in which are the great craters of Hawaii is equally remarkable. The next in point of energetic operation is the Mexican group, and its extension southwards in the high Andes, on the west coast of South America. The Mediterranean band, extending from Asia Minor by some islands of the Eastern Archipelago to Sicily, and a band on the western side of the North Pacific Ocean, may be regarded as succeeding these in importance. The number of the large volcanic craters, in some of these localities, is inconsiderable, but the eruptions are of interest.

Although less important than many, in the number of the volcanic vents and in the intensity of volcanic action, the European system is naturally of extreme interest to the inhabitants of Europe. It includes (1) two principal volcanoes, one (Vesuvius) on the southern part of the peninsula of Italy,

---

* Report on Earthquakes. Brit. Assoc. Reports, 1858, p. 65.]

and the other (Etna) much more lofty and equally interesting, situated in the island of Sicily. These are connected by (2) the group of the Lipari islands, which are constantly in a state of semi-activity. They are also probably connected, though less intimately, with (3) the volcanoes of the Greek islands. All have shown more or less activity within the last few thousand years, and must be ranked among existing volcanic vents. All are connected with the earthquake movements that have disturbed the bed of the Mediterranean and the land of Italy from time immemorial. Eruptions in one district have been preceded by earthquakes in another. There is such an amount of sympathy between two important vents that one answers to the other. When one is active the other is idle; and if both seem to be active, it is because neither of them is so very seriously.

Let us now consider the facts connected with the chief volcanoes and volcanic groups, beginning with those that are nearest to ourselves. Of these the south Italian group is the most important. It extends at present from the sea to the south-west of Sicily, where volcanic eruptions have taken place within a recent period through the whole of Sicily, and in a belt about a hundred miles wide to the foot of the Apennines, behind Vesuvius, a distance of about three hundred miles. It includes the great volcanoes of Etna and Vesuvius, and the subordinate but active volcanoes of the Lipari islands (Stromboli and others). But it must also include the semi-extinct volcanoes of Monte Volture, and it is difficult not to include those near Rome, another hundred miles to the north. The volcanic action has, in former times, extended much further northwards, and still, though in a subdued state, reaches to the northern slopes of the Apennines, near Parma and Modena. On the whole, this great belt must be regarded as nearly 700 miles in length, ranging about 400 miles NW. from Vesuvius and 300 miles SW. from the same central point. It is more usual to consider it as made up of two principal belts, one near Etna and the other in the Bay of Naples.

Etna, from its great elevation (nearly 11,000 feet), the large area covered with its lavas (120 miles in circumference, enclosing at least 600 square miles), its extremely regular and moderate slope (averaging about 8°), and the contrast it affords with the luxurious vegetation around and on its sides, is the most remarkable. The great dome rises very gradually, and the cone, containing the principal crater at its summit, is very large. The lava currents are numerous, reaching in some cases 15 miles from the point of outflow, with a breadth of 4 or 5 miles, and a thickness of 100 feet. On the sides of the volcano are nearly a hundred subordinate cones of ashes, some of considerable magnitude; one of them is upwards of 700 feet high.

Etna has been an erupting volcano from very ancient date, but the first disturbance recorded is about six centuries before the Christian era. There are records of about fifteen large eruptions between this and A.D. 72, after which there was repose for 180 years. Afterwards there were several small disturbances. The principal eruption of the fifteen was in 396 B.C., when a lava current ran 24 miles from the point near the summit of the cone to the sea, and entered the sea with a breadth of two miles. After the eruption of A.D. 72 there was quiet for 124 years, and then after a great eruption a further rest for 166 years. After the eruption of A.D. 362, there is no certain record of disturbance for 749 years. During this interval Vesuvius was several times active.

One of the principal recorded eruptions of Etna took place in 1169, when a large lava current reached and overwhelmed Catania. In 1329 there was another eruption of importance. The next dates are 1408, 1444, and 1447. After this, for 89 years the volcano was again quiet.

A great eruption took place in 1536 and 1537, followed by earthquakes a few years later, and then other eruptions, at short intervals, till 1619. Between that and 1669, when Catania was once more overwhelmed by a vast flood of lava, there were several smaller disturbances; and after 1669 till 1702 there were few considerable intervals of repose. Between 1702 and 1723 there was nothing important, but from that time to the present there has been always more or less activity. The last important eruption was in 1865, when a considerable portion of the north-eastern side of the great cone, and one of the subordinate cones (Monte Fromentu), were split by a wide fissure, and lava issued which ran several miles, and threatened to destroy several villages.

Etna connects with Vesuvius by Stromboli and several other islands of scoriæ and lava (the Lipari group), nearly north of the great volcano. It also connects with the volcanic island of Pantelleria, about 50 miles south-west of Girgenti, where there is subdued volcanic action. Stromboli is interesting, from its constant activity. It is 2,318 feet in height, rising directly from the sea, and is entirely composed of lava and scoriæ. It is never still; but no important eruptions from it are recorded. Between Girgenti and Pantelleria is a shoal which marks the position of Graham island, formed by a volcanic eruption some years ago.

Vesuvius is the principal cone of an important volcanic district, smaller at present than that of Etna, and less than 4,000 feet above the sea, but in the highest degree interesting. The actual area over which recent volcanic action is traceable extends from Vesuvius itself to beyond Ischia, a distance in all of nearly 40 miles, with a breadth of nearly 20 miles; but these limits do not include the outlying points, Monte Vulture to the east and the Ponza islands to the west (both volcanic), whose distance asunder is 150 miles.

Vesuvius had long been in a state of repose, and was not recognised as an active volcano until the year 63 of the Christian era, nor did any great eruption take place till A.D. 79, when Pliny was killed, and Herculaneum and Pompeii buried in the erupted ashes. No great eruption followed this for 124 years. After A.D. 203, the next eruptions of importance were in 472 and 512, both very serious, and the next after these in 1139. There had, however, been intermediate disturbances. Vesuvius was again quiet for 267 years, during which Etna erupted; and after 1306 there was an interval of 194 years. One of the chief eruptions of modern times was in 1631, followed in 1660 by another, very remarkable. In 1682 there was an eruption which greatly changed the aspect of the mountain by destroying the former crater; and the cone was again altered in 1696. During the eighteenth century the eruptions were frequent, and in the present century they have been continued. The last eruption took place in 1861, when eleven small cones were formed on a fissure 2,000 yards in length; and the ground between the cone and the sea, at Torre del Greco, was much disturbed by earthquakes.

It has generally happened, that during long intervals of repose of either Etna or Vesuvius, the other volcano has erupted seriously, and on a large scale. It appears, also, that Ischia, which has been tranquil for the last two thousand years, had been in activity during the repose of Vesuvius, before the Christian era; and that the numerous cones of the Phlegræan fields, between Vesuvius and Ischia, including the Solfatara, have always taken advantage of the intervals of repose of the great volcanoes to exhibit that amount of activity which has belonged to them. Monte Nuovo, one of these, was formed during the seventeenth century.

There is an important volcanic band in the Greek islands. It ranges south-east from near Athens, and includes Santorin, where there has been (1866) a recent submarine eruption in the interior of the enclosed bay of considerable dimensions, apparently an old and broken crater. The bed of the Mediterranean, between Santorin and Sicily, especially near the south of the Morea (at Cerigo), was greatly disturbed and elevated during the period that elapsed between the eruption of Etna in 1865 and that of Santorin in 1866. The history of the eruption at Santorin, and the formation of islands and promontories, accompanied by a shallowing of the water in the Gulf of Santorin, corresponds closely with that of the production of Graham's island, off the coast of Sicily. The small islands already existing in the Santorin group were volcanic, and had been formed in comparatively recent times.

Asia Minor abounds with proofs of volcanic activity of no very ancient date; but there seem to be no erupting craters, nor have there been any within the historic period. In the country east of Smyrna, indeed, there are three cones of eruption from which streams of lava have issued; and as these cones are composed of scoriæ and stand at a very steep slope, it is not likely that they can be very ancient. Many of the high peaks in the Taurus chain, and Mount Elburg itself, the giant of the Caucasus, are volcanic in their origin; but they certainly cannot fairly be ranked as among existing volcanoes, active in the modern period.

Syria, the Holy Land, and Arabia, all exhibit volcanic phenomena of a very direct nature. The borders of the Red Sea, especially in its southern part, near Aden, are also volcanic, but offer no instances of erupting volcanoes. Eastern Africa contains very lofty volcanic cones not far from the coast.

The whole of the country near the shores of the Mediterranean, on the African shore, must be regarded as free from any recent disturbances; and it is not till we pass the Straits of Gibraltar, and the extremity of the Atlas mountain chain as it extends into the Atlantic, that we again meet with volcanoes. In the group of the Azores, the island of Teneriffe presents us with a noble cone, rising more than 12,000 feet above the sea, and with a crater of no ancient date. Lava currents have flowed in comparatively recent times from this cone; and in the same island there are not less than six other cones, all volcanic, although none of them have erupted recently. In the Canary Islands, still nearer the north-west coast of Africa, there are several volcanoes. None of them are in actual eruption.

In the Cape de Verd Islands is one volcano still active, and others of recent date. Not far off is a part of the ocean where there is proof of recent submarine action on a grand scale. Further on, the Island of Ascension exhibits a multitude of volcanic peaks; and St. Helena, to the south-west of Ascension, has similar indications. Nearer the American side of the South Atlantic is the volcanic island of Trinidad, and to the south is Tristan da Cunha, both volcanic. Thus, parallel to the coast of Africa there are many proofs of the existence and recent working of a very great and efficient volcanic activity. Within Africa itself, except on the east coast, as already described, there seems no indication whatever of volcanic energy. That vast, compact land, has been brought into its present position without being subject to the convulsions that generally accompany volcanic action, when from time to time the communication between the interior of the earth and the surface is intercepted. Australia, in this respect, resembles it.

But it is not only in the southern part of the Atlantic that volcanic islands are recognised. The Icelandic group, near the Arctic circle, and that of Jan Meyen Island, within it, are in some respects as interesting as the Mediterranean group, including Etna and Vesuvius.

It is, indeed, to its volcanoes that Iceland owes its chief interest, and in no part of the world is more terrible evidence of volcanic agency to be seen. Most of the greater mountains of the island are still volcanoes, and the whole island owes its birth to volcanic upheaval. Hecla is the best known example, and this chiefly because it lies to the south of the island, and can be seen by passing ships, but it is very far from being the most destructive of the Icelandic group. It is, however, upwards of 6,000 feet in height. On an average, there has been an explosion somewhere in the island every thirteen years, beginning at the earliest period of accurate history. A large part of the interior of Iceland is little known, and rarely if ever visited. It is, no doubt, very inacessible, but it is certainly remarkable, that in a land where bravery and enterprise have never been wanting, a region some 3,000 square miles in extent, lying in the south-east corner of the island, should have been so little penetrated by man. In that wild and almost untrodden desert stand some of the most destructive craters on the surface of the globe; and out of this solitude, seas of molten lava have at various times flowed over the pastures and laboriously cultivated fields of the inhabitants. Hills have been thrown up, water-courses cut deep in the hills filled to the brim, and long reefs and islands cast far out into the sea, by the successive floods of lava. One stream is 50 miles long, 15 miles broad, and 600 feet deep; and it has been calculated that a single volcano in that wilderness threw out, during one eruption, 50 to 60 millions of cubic yards of material. The accounts which have been handed down of this event present to us a picture too terrible almost for belief. With a wide-spread destruction of the land, the depths of the sea were invaded, and the fish (the Icelanders' chief means of subsistence) driven from the shore. The flames broke out even through the waves in the line of movement, and the sea was covered with pumice for 150 miles. A thick canopy hung over the island for a year, and the winds carried the ashes over Europe, Africa, and America. The very sun was darkened, and showed only as a ball of fire; while frightful hurricanes, hail storms, thunder and lightning, added their horrors.

Hecla is in a state of almost incessant disturbance, either by actual eruptions or those smaller but singularly picturesque and striking phenomena of boiling springs for which the island is celebrated. The Geysers, however, belong to the second or subdued stage of activity. Beyond Hecla is Jan Meyens Island, where there are two volcanoes.

On the continent of Asia there is a remarkable but very little known line of volcanic activity, of which the mountain of Thian Chan (celestial mountain) is the central part. It is still doubtful whether they are true active volcanoes. The case is far different on the southern and eastern coasts. The islands near the Malay peninsula, commencing with the Andaman group and the Nicobar islands, and extending through Sumatra into Java, are all volcanic, and the volcanic force attains there the condition of intense energy. Along the whole length of Java the volcanic mountains are so close that it is difficult to distinguish between the various groups. This is the case for at least 700 miles. In this island the volcanoes range from 5,000 to 13,000 feet in height above the sea. A branch of the volcanic belt proceeds northwards through the Phillippine Islands and Formosa, connecting by Japan with the Kurile Islands and Kamtchatka. Another branch connects with New Guinea, and so with the Australian group (off the eastern coast) and New Zealand, where Mount Egmont rises to a lofty elevation and is one of the noblest volcanoes in the Pacific.

Of Hawaii, in the Sandwich group, one of the principal volcanoes of the islands of the Pacific, we have already given some account. It may possibly connect, by a curved line, with the Marquesas group and the Society Islands, both of which are volcanic, though the cones and craters are less considerable than in the Sandwich Islands. Across the Pacific we have the volcanic group of the Galapagos Islands; to the south is Easter Island, and much further south, in the Antarctic Ocean, a large tract of land, perpetually enclosed by ice, vomits forth fire and melted rock from a number of lofty volcanic cones. Crossing the comparatively narrow sea between South Shetland Island and Cape Hoorn, we come to volcanoes again in Tierra del Fuego, where there are three cones, of which the loftiest is nearly 7,000 feet in height. In this manner commences the magnificent volcanic range, which is continued at intervals throughout the whole chain of the Andes to the Rocky Mountains.

The northernmost of the Patagonian volcanoes is in latitude 54° 27′ S., and the next to the north occurs on the coast of Chili, in latitude 43½° S. The Chilian range includes about twenty volcanoes, within a distance of about 700 miles, the loftiest of them being Aconcagua, whose height is 23,200 feet, but too little is known of the physical history of this district to enable us to determine very distinctly which of these volcanoes have been in recent activity.

North of the Chilian range, at the distance of 540 miles, commences that of Peru and Bolivia, which, in a distance of 360 miles, presents to us twelve volcanoes, one of which, that of Viejo, is upwards of 20,000 feet in height, and another as much as 22,000 feet. About 800 miles north of the northern extremity of the Peruvian range commences that of Quito, where seventeen magnificent cones, ranging from 13,000 to 20,000 feet above the sea, are crowded into a distance whose extreme length is less than 400 miles. Amongst these, Cotopaxi throws up flames 3,000 feet above the brink of its crater, which is nearly 19,000 feet above the sea level, and its bellowings are heard for hundreds of miles, reaching even to the mariner as he sails upon the ocean past the coast line of this part of America. In this portion of the Andes the chain is for the first time distinctly double, and we have already described the lofty plains, bounded on each side by these gigantic cones.

From the northern extremity of the eastern range of the Quito volcanoes two branches extend, one to the east, connecting this range with that of the West Indian Islands, where ten volcanoes have been described between latitude 12° and 17½° N., and longitude 61° and 63° W., the other forming the Guatemala group, which, following the western line of coast, first of South America and then of the isthmus connecting the two Americas, commences in latitude 9° 35′ N., and, in a distance of 400 miles, presents 38 volcanoes, some of which, as Coseguina, have been the seat of frightful eruptions within a comparatively recent period. The southernmost of these volcanoes is less than 400 miles from the northernmost of the Quito range, and that furthest to the north is within 150 miles of the Mexican series which extends westwards, and contains seven volcanoes in a distance of 450 miles. The Guatemalan cones are most of them under 13,000 feet in height, and are, therefore, lower than those of Quito to the south or Mexico to the north, most of the latter rising to a much more considerable elevation, and one of them (Popocatepetl) being nearly 18,000 feet high.

From this point northwards to latitude 26° N., a distance of rather more than 400 miles, no volcanoes have as yet been described, and thence to latitude 60° we are told only of ten, some of which are doubtful. A few of these range to a very considerable altitude, one of them, Mount Elias, being estimated at nearly 18,000 feet. In this latitude the volcanic range, commencing a westerly direction, crosses the straits which separate North America from Asia by a multitude of islands, rising to very different but often considerable heights above the sea, and consisting of not less than thirty-five, between longitude 162½° W. and 179° 20′ E., a distance of only 600 miles. From the westernmost of these, which are the Aleutian Islands, to the coast of Kamtchatka, where the volcano of Schiwelutch rises as a beacon 10,500 feet above the sea, is a distance of about 600 miles, and there appears to be a corresponding range to that on the coast of South America, commencing with the twenty-one volcanoes of Kamtchatka, between latitude 51½° and 58° N., and continued by the volcanic series of the Kurile Islands, already alluded to.

In many volcanic districts there is evidence of a certain amount of subdued or diminished activity at a distance from the principal points of eruption. This dying out of volcanic force is generally limited to those places where there appears to have been more energy displayed within a comparatively recent period, and is therefore an interesting part of the history of volcanoes. There is no record of volcanic disturbance having actually originated in any part of the world within the human period, nor is there much probability of such an event. All the evidence seems to show that the main directions of volcanic force are coincident with main elevations of land, and have been determined from a very early period of the earth's history. The instances of diminishing action are probably due only to slight changes in the direction of volcanic activity, owing to local accumulations of material near the surface. There are two very remarkable illustrations of inferior volcanic energy, one consisting of eruptions of heated water—the other of the phenomena of mud volcanoes or *salses*, as they are sometimes called. Both require notice, but concerning the former, there has already been given a sufficient account in the chapter on springs.

Mud volcanoes are very singular, and though long known, have hardly, perhaps, been sufficiently considered in their relation to decaying volcanic energy. They occur only in certain limited areas, though they are both more frequent and more important than has generally been supposed by geological writers. It is probable that they may in some cases have commenced recently, though most recorded instances are only repetitions of old outbursts. Those best known in Europe are comparatively small, but there are others of large dimensions also recorded. Let us consider a few examples.

At Paternó, in Sicily, close to the south-western extremity of the Etna lavas, a mud eruption took place in the month of January, 1866, in a plain below the hill on which Paternó is built, and not far from the bed of the Simeto. It commenced by a slight earthquake and the outburst of a strong jet of water through a crevice in underlying lava. The water at first rose about six feet in a strong jet, at boiling temperature. Several such jets followed, the volume of the first jet diminishing, though the total quantity of water erupted was increased. The temperature of the erupted water diminished slowly from the commencement. There was no noise, no flame, and no visible vapour, but much gas bubbling through the water, and some naphtha.

The water issuing was muddy, but no stones or lumps of solid matter were erupted. After the removal of the mud the water remaining was found to be intensely salt. A considerable quantity of petroleum of dark-green colour floated on the surface of the water.

The mud volcanoes of the Crimea and Taman are very numerous, and all within a belt of country nearly parallel with the axis of the Caucasus. Similar phenomena exist near Teflis, half-way between the Black Sea and the Caspian; at Baku, on the western shore of the Caspian; and in islands near the eastern shores of the Caspian.

The erupting cones are all of the same general character. The mud is poured out very slowly from the top, and is tenacious, and often as thick as treacle. Bubbles of gas accompany the mud. The various cones are accumulated from the material erupted, and in no other way.

On the eastern side of the straits of Kertch, and within the peninsula of Taman, there is an extensive group of conical hills of marl and mud, due to the issue of mud under circumstances identical with those just described. They occupy an area of many square miles.

We owe to Pallas a detailed account of an eruption that took place in this peninsula towards the close of the last century. This eruption resulted in the formation of a large conical hill visible from Kertch, which is about fourteen miles distant, and a prominent object to vessels passing through the straits. The cone is now much weathered. It consists of clay, with small angular lumps of limestone and small fragments of earthy oxide of iron. There is a depression or crater at the top. The height is about 250 feet.

Several miles from this old cone, towards the east, is a remarkable group of mud volcanoes at present (1865) in activity. There are four of large size, all issuing mud. These hills are about the same height as that described by Pallas, and form a considerable group. Like the others, their slopes contain numerous fragments of iron oxide. A ridge, some miles long, behind and near the village of Taman, is also entirely formed of erupted mud; but these mud hills are detached from the group just described. Indications of mud volcanoes extend eastwards beneath the Caucasus to the Caspian, and westwards towards and into the Putrid Sea, so that the belt of country characterised by these phenomena on the southern slopes of the Caucasus is almost unbroken. It extends across the low flat plains of the south of Russia to a very great distance, and is everywhere marked by the same peculiar condition, and with similar proofs of communication with the interior of the earth. The distances referred to are roughly as follows:—From the eastern Caspian to Teflis, about 500 miles with various connecting links. From Teflis to Anapa, nearly 400 miles without such links. From Anapa to the Putrid Sea, unquestionably connected by similar phenomena, 200 miles.

Crossing a large part of eastern Europe we do not again meet with distinct indications of mud volcanoes till we reach North Italy, where there are some well-known and remarkable examples at Sassuola and elsewhere, on the northern slopes of the Apennines, in the provinces of Modena and Parma. These have exhibited all the phenomena above described within the last century, and they are also described in classical works. From one of these there have been eruptions of solid matter, and even of lignite. On the other side of the Apennines the boracic springs near Volterra are of the same nature, but true active mud volcanoes have not been found between this and Sicily. There, both on the slopes of Etna and near the southern coast at Girgenti, they recur with the usual characteristics.

From the Caspian Sea, eastwards, at various places on the northern slopes of the Himalayan chain, and so into China, mud volcanoes have been noticed. They appear to exist on a very large scale in Java. They belong also to the volcanic system of the new world, where the Mexican examples are recent and very extensive, the phenomena being nearly the same as those described. The most remarkable and instructive of those that have been less prominently referred to by geological writers are those in Trinidad, others occurring in California, and some in Iceland.

On the whole, then, it may be concluded that mud volcanoes represent in a very striking manner the declining stage of volcanic activity, but they do so under conditions which are not by any means universal. There are many volcanic districts where there does not seem anything of the kind: many, where hot water alone or thermal mineral springs are ejected, others where there are special minerals, as borax, in exceptional abundance. True mud of the ordinary kind may be erupted, thin or thick, with or without foreign substances, and at temperatures varying between a heat much exceeding the boiling point of water and the equivalent of the mean annual temperature of the district. The phenomena, also, though they vary in details, are on the whole constant in their nature and in the order of their occurrence. The eruption may be described as commencing with heated water and gases, occasionally accompanied by mud, and even considerable fragments of rock. The eruptive force exerted being comparatively small, the result in this respect is also small; but, as in other volcanic districts, the force exhibits itself by forming crevices in the earth, along certain lines of least resistance. In mud volcanoes the steam issuing from the crevices has been condensed into water before it reaches the surface. The erupted water also brings with it such earthy substances as it meets on its way, and thus mud, more or less thick, issues from the crevice instead of lava. With regard to the carbonic acid and other gases, the thin mud allows of their passage to the surface in bubbles.

If we duly consider the mode of distribution of volcanoes on the earth's surface it is impossible not to be struck with the fact, that almost all indications of recent volcanic activity are to be found either along certain lines of coast or in islands of moderate size. All the vast areas of the interior of the great continents—with the exception already alluded to in the case of Asia—(a very small exception in so large an area) are so near the sea as to suggest an explanation of the phenomena that shall have reference to water. Without theorising on the matter we may point out that, while on the one hand the ready access of water from the sea to those vast cavities in the interior of the earth with which volcanoes communicate, may excite chemical action, and supply the steam and water so abundantly given off; so, on the other hand, the volcanoes may be near the sea, merely because those lines which limit continents may also be those of fracture, and may well be supposed to open a communication with the interior.

According to this view the water needed for the steam erupted may be derived from infiltration from the rocks that form the land as well as those under the sea. The direct access of sea-water in its normal state is improbable, inasmuch as the sea-water would become to some extent filtered in passing through rocks. On the other hand, some at least of the contents of sea-water, especially common salt, are not uncommonly to be found either in the substance of lavas, or in the fissures of lava through which gases pass.

That volcanoes are connected with terrestrial phenomena of a very recent date and with what goes on daily on and beneath the immediate surface, is evident from the nature of the material erupted. More than once, minute organic bodies have been found in volcanic dust,—this dust being nothing more than the very minute fragments of the matter sent out from within a crater. Such fragments are of course confined to those bodies which, like silica, may undergo long exposure to great heat without change. They are siliceous spicules and the cases or cells connected with the most simple forms of life. But they are present in abundance. Earthy calcareous matter is also not unfrequently found entangled with the scoriæ, or ashes of volcanoes. Charcoal has been erupted from mud volcanoes.

There has been much difference of opinion as to the mechanical origin of volcanoes. While Humboldt and Von Buch, with many very eminent and intelligent observers, have insisted on discovering proofs, in various instances, of some upheaving force thrusting up a portion of the earth's crust in a dome shape, and continuing this till a considerable hill was formed as a nucleus, round and upon which the subsequent volcanic products have been collected: others, among whom we may name Sir Charles Lyell, Mr. Poulett Scrope and Mr. Darwin, all very familiar with such phenomena, believe that volcanic cones consist of the matter erupted, heaped round the place of eruption, and are quite independent of any upheaval. The special case quoted by Humboldt,—that of Jorullo, in Mexico, is now believed to afford evidence altogether opposed to the view advocated by the great geographer, and the weight of facts seems much in favour of this latter theory, which is also more in accordance with the non-sensational geology of the present day. This is, however, rather a matter of discussion for the geologist than the physical geographer.

Besides the volcanoes that are still in an active state, those which have been known to erupt within the limits of human history, and those of which there is independent evidence that they belong to the existing period. though no records exist, there are many parts of the world where there is proof of volcanic activity, though there remain no volcanoes from which the eruptions have issued. There are other districts where volcanic cones and craters exist, where ashes are heaped, and where currents of lava have once flowed over the broken walls of depressions still traceable, but where all is now silent, and which are far removed from any of those districts that belong to either groups or linear systems of volcanic influence. Such calm and dead volcanic cones are regarded as extinct, and experience would seem to show that the strength of subterranean action had there become gradually dissipated. It would also seem that this has not been in spite of resistance, but in consequence of a wearing out and exhaustion of the material, or perhaps the result of a cessation in that place of the action of the forces that produce the phenomena.

Among the most remarkable instances of these extinct volcanoes, we may first mention a group often described, and sometimes believed to have been in activity in comparatively recent times. We mean the volcanoes of Auvergne, in Central France. A large number of volcanic cones and craters are to be found here ;—the cones are composed of scoriæ ; the craters are still to be measured and examined, except where they are filled with water and converted into pools ; and floods of ancient lava are still to be seen, precisely identical with those that were poured out from Vesuvius or Etna a few years since. No one, visiting the country, can for a moment doubt that he is in a volcanic district, though the fact that there has been no volcanic disturbance since the country was settled, is also certain. On the north-east coast of Spain, there is another equally well marked example of extinct volcanoes. Within a comparatively small area a number of cones and craters, with currents of ancient lava, may be traced, and the country around bears marks of having been subjected to subterraneous disturbance. Other examples of a similar nature are known on the banks of the Rhine, near Bonn, and others in the interior of Germany. But nothing of the kind has been described in many wide tracts of land, far removed from the ocean, in which, also, there are no modern volcanoes. In such countries, if indications of volcanic action exist at all, they consist in beds of lava, often of considerable thickness, but spread out as if under the pressure of a heavy column of water, and with no appearance of volcanic cone or crater.

Volcanoes, whether in groups or on an extended lineal axis, appear to have certain relations with one another. The activity of one volcano is almost of itself proof that no adjacent one will be other than dormant. In the Andes, where the line of energetic activity is very long, this has been most strikingly shown, and strong proof is thus afforded of the really partial and local character of all phenomena of this kind.* The cavities in which that chemical action takes place, which results in the melting of rocks and the formation of that peculiar mineral glass or slag we call lava, may be very large, extending for hundreds, or even thousands of miles, and they must be many thousand yards beneath the surface, at least in some cases. Their breadth, however, need not be great, and thus their area may be a very small fraction indeed of the whole surface of the earth. Each group may be independent, and the depth or distance from the surface may be altogether different, even in the nearest adjoining groups. It is only by conceiving this peculiar state of the earth's interior that we can at all explain the phenomena of volcanoes. Important they may be, and no doubt are, in the districts where they exist, but it is hardly likely that they have much to do with the original upheaval of continents, or the determination of the form and distribution of the great masses of land on the globe. They are, however, connected with earthquakes, and in the next chapter we shall see in how singular a manner these violent undulations of the earth's crust originate in cavities whence volcanic eruptions issue, although their effects are felt at enormous distances, even from the outermost verge of any district showing marks of volcanic energy.

---

* In the eruption that took place recently at Hawaii, the great crater of Kilauea, filled with extremely fluid lava, does not appear to have been affected by the eruption at Mauna Loa, at a distance of 20 miles.

CHAPTER XVII.

EARTHQUAKES.

While volcanoes afford visible proofs of the activity of chemical forces within certain portions of the interior of the earth, and suggest that there must be large cavities, continuing at intervals, and in some broken and interrupted way connected for hundreds or even thousands of miles, it is well known that wide tracts of the earth, not only near volcanoes, but far removed to all appearance from their influence, are subjected to vibrations, more or less severe, of the actual crust of the earth. That these vibrations, or *earthquakes*, are in many cases very clearly connected with volcanoes—that they precede and accompany volcanic eruptions—that the earthquake either precedes or follows the eruption—and that the cessation of ordinary volcanic action is very generally succeeded, after a longer or shorter interval, by an earthquake,—there is no doubt. On the other hand, it is equally certain that earthquakes sometimes originate and are chiefly felt in countries where there are no volcanoes, and where all varieties of volcanic rock are absent. They are, therefore, phenomena that require separate consideration, and what we can learn concerning them may help to suggest something concerning the condition of the interior of the earth, as well as an explanation of the phenomena themselves.

The connection of earthquakes with volcanoes in volcanic districts is clear and unmistakeable. In the European group history is eloquent in illustrations. The neighbourhoods of Etna and Vesuvius have suffered from time to time from severe shocks, which are regarded as the precursors of eruptions. The singular volcano of Stromboli had a brief interval of repose from its almost incessant activity immediately before a series of severe earthquakes, that disturbed the whole country around, in the year 1783. For a long time the volcano of Pasto, in Peru, had continued to emit a dense black smoke from its crater. This ceased for a time, and the terrible earthquake of Rio Bamba occurred, during which forty thousand persons perished. A remarkable instance, perhaps the most remarkable on record, took place in the years 1811 and 1812, showing a subterraneous connection beneath the bed of the Atlantic between the European and central American lines of volcanic action. In the year 1811 an island arose in the Atlantic, from about 120 feet of water, amongst the Azores, the rise of the island being accompanied by violent earthquakes and eruptions of smoke and flame. Commencing about the same time, there were severe shocks in the island of St. Vincent, near one of the most active volcanoes of the West Indian group, which had not erupted for about a century. These shocks extended also through the Mississippi valley, and were widely felt in North America. In December, 1811, and March, 1812, severe earthquakes were experienced in the Caraccas, the shocks in both cases continuing for some days, and ending with the destruction of the city. As a termination to these disturbances, the volcano of St. Vincent, after a long interval of repose, burst out with a tremendous explosion, and continued to erupt for a long time, during which there were no more earthquakes within the area formerly disturbed. Numerous examples of the same kind might be given, and we may regard it as an established fact, that whatever be the cause of earthquakes, and however the active energy of chemical forces and heat may act in the interior of the earth to produce volcanic eruptions, there is in so far a relation between them that the same force which at one time is only enabled to produce a concussion and vibration, by something of the nature of an explosion, becomes at length powerful enough to rend asunder the thick coating of rock that forms the roof of the cavern in which the force acts, and continuous enough to force up a continuous stream of molten rock for weeks together.

An earthquake is the result of a vibration or concussion produced within the earth by some explosive force. It must originate in a comparatively small area, and the chief force of the explosion must expend itself in that area. The area disturbed may be one of a series of cavities having great linear extension, or it may be part of a large district of any form, in which are numerous cavities or spaces more or less isolated.

The explosion may be single, or it may be repeated many times. It may be very sudden and rapid, and of extreme violence, or it may be less rapid, and the force produced may tend more towards upheaval than fracture. The force, however, must act in a way not unlike that of gunpowder exploded in a mine, or steam bursting a boiler; and the comparisons drawn from such instances are found to be—as might be expected—both suggestive and explanatory.

Where they are felt at the earth's surface, earthquakes are of three kinds,—undulatory, perpendicular, and horizontal; the latter frequently appearing to be rotatory or verticose. The first are the most common, and the least mischievous; the second, much more rare, and far more destructive. The third are altogether exceptional; but when they occur in the neighbourhood of towns, they are altogether unparalleled in the disastrous catastrophes and the appalling loss of life that accompany them. The first are mere undulations, heaving the ground at any one place upwards and sinking it downwards, and producing the same, or nearly the same, result at a vast number of places along a certain definite course on the earth's surface. The second resemble the explosion of a mine; they consist of a sudden upheaval—a thrust upwards—but with no undulation. The third are complicated, including a direct and sudden upheaval, with an advancing wave, and this complication produces a mixed motion, like that of a steamer advancing through a cross sea.

The destruction to human life caused by the greater earthquakes is very serious. Upwards of 60,000 persons perished during the great earthquake of Lisbon, in November, 1755; but in this case the chief mischief was caused by a high wave, caused no doubt by the earthquake, but coming in from the sea. By an earthquake in Mexico 10,000 persons perished. In Calabria 40,000. In Syria, on one occasion, 50,000. In the same country, in the time of Tiberius, A.D. 19, it is considered that 120,000 persons were destroyed. In the year 526, 250,000 are said to have perished at Antioch; and seventy-six years afterwards a second earthquake destroyed 60,000. At Messina, in 1692, as many as 74,000 persons perished; and at Quito, in 1797, 40,000 victims were sacrificed to this terrible agent. Lastly, at Mendoza, not very long ago, the whole city was destroyed, and the loss of life was estimated at 60,000. On the whole, it is not too much to assert that several millions of human beings have been suddenly swallowed up in this way within the last four thousand years; and it cannot be supposed that animals and vegetation have escaped a proportionate destruction.

It cannot, then, be thought extraordinary that the phenomena of earthquakes are exceedingly striking, and in the highest degree alarming to all living beings. Domesticated as well as wild animals, the birds of the air and the fishes of the sea—all seem alike terrified; and all, with man himself, civilised and uncivilised, become deeply affected when the larger earthquakes take place. Nor does frequent repetition of these convulsions in any district render those exposed to them careless or indifferent. On the contrary, the more frequent they are the more alarmed do people become. It is not easy to explain this, but it is a notorious fact; and a brief account of the sensations and mechanical accompaniments is necessary to familiarise the reader, who has had no experience of a serious convulsion, with the nature of the case.

Earthquakes are sometimes preceded or accompanied by a peculiar state of the air and weather, by rolling, detonating, and other noises, and by marked electrical phenomena. But these cannot be regarded as essential or necessary, though the observations that include careful records of all these matters are both interesting and valuable. The kind of noise that occurs is different in different places. Sometimes it is a rolling, rumbling sound, like the moving of heavily-loaded waggons over a hard road—sometimes it is like the clinking of chains—sometimes it resembles thunder close at hand—and now and then it has been described as clear and ringing, as if obsidian or other vitrified masses clashed together, or were shattered in subterranean cavities. The imagination is, however, so apt to exaggerate sounds of this kind, and to discover fanciful resemblances that have little foundation in fact, that we can hardly accept all these descriptions. It is, however, recorded that on one occasion, in the Caraccas, a noise resembling thunder was heard nearly or exactly at the same time over an area of 40,000 miles, without this noise being followed by an earthquake. At this time the volcano of Cotopaxi, more than 400 miles distant, was commencing an eruption. It is also said, that at the great eruption of Cotopaxi, in 1744, subterranean noises, resembling the firing of artillery, were propagated through the earth without earthquake for a distance of more than 400 miles.

It is often the case, that a multitude of minute vibrations mark the main direction of some axis of disturbance, better than the observations made where earthquakes are much more severe.

The distribution of earthquakes in space is by no means identical with the distribution of volcanoes. It is not, indeed, so easily to be estimated, nor can it be so well described, for the actual point at which an earth vibration commences,—that at which the explosive movement takes place,—cannot always be determined. It is sometimes beneath the sea. It is sometimes in parts of the earth beyond the range of civilisation, rarely visited and little known. And the area of disturbance is often quite unknown. As the earthquake, moreover, leaves little or no mark behind it, and is in this respect altogether unlike the volcano, it is evident that where no observation has been recorded at the moment the evidence is lost for ever. On the other hand, earthquakes are much more widely felt and more numerous than volcanic eruptions.

In estimating the importance of an earthquake, many things must be taken into consideration. The intensity of the shock at a given place may be very great, but the area over which it is felt comparatively small. A multitude of smaller shocks may occur in one place; a few smart shocks at another. As a rough approximation it may be estimated that the areas disturbed in the case of great earthquakes are circles, or ellipses, whose diameters or longer axes measure from 1,000 to 1,200 miles. These are rare; perhaps not usually occurring more than once or twice in a century, over the whole earth. Other and smaller earthquakes, which we may describe as of the second class, affect areas not exceeding 500 miles in diameter, and are far more common. Others, again, are not felt more than 100 or 150 miles, and may also be regarded as local. These form a third class. It must be understood, that while thus, for convenience, grouping the earthquakes whose limits are known, there is no real division in nature, nor is it always possible to decide to which class any particular earthquake may belong. Of the first class, the great Lisbon earthquake of 1755 may be taken as an example. Of the second, examples are frequent in the Mediterranean basin. Of the third, there are instances not unfrequently in our own islands.

Although the limits of an earthquake are theoretically indeterminate, there is a practical limit, measured by the senses, which must always be recognised. This limit depends not a little on the nature of the rocks through which the shock or vibration passes, and thus, from a central point, the vibrations are felt at very different distances in different directions. Looking at the matter in this light, we may obtain a notion of the distribution of earthquake action, or at least of the directions which earthquakes seem to take, and of the connected points of earthquake centres. These, as might be expected, are somewhat influenced by the line of mountain and valley in a great continent.

Commencing with the north-eastern shores and islands of the Atlantic, there is a belt of weak earthquake action that includes Iceland, Ferro, Shetland, the south-west coast of Norway, nearly as far as Christiania. This band possibly extends to Greenland and Jan Meyen, but the earthquake history of this part of the world is not known. Another band extends north-west from the lakes of Sweden into Russian Lapland, and perhaps to the Dovre fjeld mountains. An important band in the south of Europe stretches from Portugal to the Azores, and is connected with a band through the Canaries and Madeira, and again with the Barbary coast and Morocco.

From Tunis, on the Mediterranean shores of Africa, a narrow band of intense disturbance stretches through Sicily and Italy, sends off a spur to the west, through the Piedmontese Alps and southern France, along the whole line of the Pyrenees, to the northern coast of Spain, and widening out over the central Alps, covering a large part of central southern Europe, extending east and west from Lyons to Vienna, and though narrowing towards Strasburg, reaching northwards over the whole Rhenish system, and dying out in the plains of Holland, where small earthquakes are not unknown. An imperfect belt connects the British Islands, western France, and the Channel Islands with both these areas, and is occasionally affected by earthquakes, almost entirely of the third class.

Much obscurity exists as to the extent of earthquake action in the Carpathians and Balkan range. The small population and the absence of intelligent observers in those districts are very unfavourable to observations, but Poland and the Vistula valley to Riga are disturbed, and both the Austrian Alps and the vicinity of Constantinople are so frequently shaken, that it is probable there are many more earthquakes in those districts than have been recorded. A broad band of earthquake action extends also from the Greek Archipelego to Constantinople, extending through Asia Minor and Palestine, and reaching the valley of the Lower Nile, the shores of the Red Sea, and further south in Arabia. From the Gulf of Scanderoon, by Aleppo and Mosul, to Lake Van, and the south of Ararat to Shirvan and Baku, on the Caspian, there is another wide and energetic band, probably joining the Caucasus, and connected with the occasionally disturbed districts of the Oural. There are other bands not less important, but ill-defined, connecting Persia and India, and connecting with the well-known and energetic line of disturbances in Northern India. This latter band, bounded on the north by the Himalayan chain, ranges nearly parallel to it, from Cabool to Calcutta, and the Gulf of Cutch. We have also a greatly disturbed but unknown area in Central Asia, reaching, in China, to Pekin and Canton, and this connects with the most formidable earthquake and volcanic region on the globe. "Stretching in a vast horse-shoe convex to the south, from Burmah and Pegu, and surrounding the great island of Borneo, with an intervening belt of sea, and reaching round to Formora, on the north-west, we have an almost continuous girdle of volcanoes and lofty mountains. Every island of the group, including Java and Sumatra, Celebes and Mindanao, is shaken with earthquakes, the most formidable and frequent, and we can point to no spots upon the whole earth's surface upon which seismic energy is exhibited with an intensity equal to that of Luzon and Sumbawa."*

To the north of this remarkable district we have bands of active earthquake movement, reaching from Japan through the Kurile islands, to Kamtchatka; and on the opposite shores of the Pacific are those of the Rocky Mountains and California, Mexico and the South American Andes, whose influence is felt on the oceanic, rather than the land side of the chain, owing to the compression of the mass of the land checking the wave. This South American band extends into the Gulf of Mexico, and connects itself with the band affecting the West

---

* See Mr. Mallet's "Report on the Facts and Theory of Earthquake Movements." Final Report in British Association Reports for 1858. To the general conclusions in this Report we are chiefly indebted for this account of the distribution of earthquakes in space and time.

Indian islands. Besides the areas already alluded to, the valleys of the Missouri and Mississippi, and the northern lakes and valley of St. Lawrence, are all occasionally exposed to disturbances, chiefly or entirely of the third class.

There is a small earthquake band affecting Western Australia, and probably reaching Van Diemen's Land. The interior of Australia and the continent of Africa are believed to be very little subject to earthquake movements, but these, as well as very large portions of Asia and South America, are too little known to enable us to give a very decided opinion on this point. It must also long be doubtful whether, and if any, what lines or belts of earthquake activity exist in those large regions that are covered by the sea, and only traversed occasionally by ships. It is considered probable that there are fewer earthquakes in a given area covered by the sea, than on land above the sea level.

Generalising these groups of facts it may be remarked, (1). That there seems a preponderance of earthquake action in the temperate and torrid zones on both sides of the equator, but the observations in the Antarctic high latitudes are too imperfect to render this at all certain. (2). That bands of superficial distribution exist, but are of variable and often great breadth, reaching from 250 to 1,000 miles transversely; (3). That the bands on the whole seem to follow the lines of elevation which separate the great basins into which the surface is divided. It must be remarked, however, that earthquakes are occasionally felt in districts far removed from any of the recognised bands, and that these may even be exceedingly energetic.

We come next to consider the distribution of earthquakes in time. To obtain any knowledge of this it is necessary to obtain all possible records of such movements as have been observed, and, estimating each according to its value, tabulate the whole. Very elaborate tables have been prepared and published, partly by Professor Perrey, of Dijon, and partly by Mr. Mallet. The latter has prepared a catalogue *raisonnée*, completed to the end of 1842, and the former a catalogue which brings up the history to 1850. Both are before the world, and the two together embrace between 6,000 and 7,000 separate recorded earthquakes over every part of the known globe, both on land and ocean. Of these 58 are previous to the Christian era and 197 between that time and the end of the ninth century. All these were, of course, very great earthquakes, demanding attention from all who came under their influence. Only 532 are recorded in the next six centuries, which include the period commonly called the middle ages. During the next three centuries the number recorded amounts to 2,804, and in the first half of the present century it has increased to 3,240. It is necessary to mention these figures to give the reader an idea of the progress of observation rather than of the actual number of earthquakes that have happened, except in a very limited sense and so far as Europe is concerned, within the present century.

It may help still further to place this matter clearly before the reader to mention that, of the early earthquakes, up to the end of the fifteenth century, about eight in every hundred of those recorded were so destructive as to reduce cities and towns to rubbish, and destroy much human life. Within the next three centuries less than four in a hundred were of this kind, while in the present century little more than 1½ per cent. of the recorded earthquakes were of the first class. It results from this statement what, indeed, we might safely have assumed, that in proportion as means of communication have improved the lists have been gradually becoming more perfect and more inclusive; that many more of the earthquakes of the second and third class, in proportion to those of the first, have been noticed, and though it is by no means the case that we have even now a complete record, it may be assumed that, in recent times, few really important disturbances have been neglected that have affected the land in the northern hemisphere. The number of these as recorded is 3,076 out of the 3,240. If, then, it is the case that the accounts of the first half of the present century give an approximate average of the truth, we may conclude that within that period there has been on an average about sixty earthquakes per annum, or rather more than one every week. Most of these were small and unimportant, but of great earthquake disasters there has been on an average one every eight months. Too little is known of the land in much of the southern hemisphere to justify a corresponding estimate for that part of the world; and of the earthquakes at sea it has already been observed that we know scarcely anything.

A comparison of the earthquakes, with a view to determine the relative frequency of the different kinds, and to discover, if possible, any order or law that governs them, seems to show that they exhibit periods and intervals of something approaching regularity. Thus it results that the smallest paroxysmal interval is a year or two, but the average interval involves from five to ten years of comparative repose. Under any circumstances, however, there is evidence of alternation of activity and repose, both when we consider the earthquake shocks in special localities, and over the whole of a very large area, including several bands of earthquake activity. On the whole, also, it seems that when the intervals of repose are shortest there are fewer earthquakes of the first class. In reference to this question it is worthy of notice that, in each century for many centuries past, there have been two periods of chief earthquake intensity, one greater than the other, occurring about the middle of each century, (from the fiftieth to the sixtieth year), and the other towards the end of each. Thus, within the first period in the eighteenth century there was the great Lisbon earthquake, and within the second the great Calabrian one. In the seventeenth century there were a multitude of great disturbances in the middle and the great Jamaica earthquake at the end. In the sixteenth century the middle part was marked by great earthquakes in China, and also in Europe, and the latter by numerous severe shocks in the Azores. Thus we have observed an interval of about a century occurring between the very greatest paroxysms, and a period of from thirty to forty years between each greatest paroxysm and another of smaller magnitude succeeding it. In the middle and most intense paroxysmal period, a large number of earthquakes are crowded into a small number of years, while in the second and less intense period the number is smaller, and the number of years over which they are spread is greater. Beyond this generalisation is another, more faintly indicated. It would seem that the 1st, 5th, 9th, 12th and 18th centuries have been those of chief activity, and the 3rd, 7th, 10th and 14th those of least activity.

There are some curious results of an examination of the earthquake catalogues that we must now consider. And first, in reference to special localities, and the various seasons of the year. The localities are grouped according to the bands already indicated. Thus, in Europe and the adjacent countries, we have the following areas of earthquake action, as suggested by Professor Perrey.

1. Scandinavian peninsula and Iceland.
2. British Islands.
3. Spanish peninsula.
4. France, Belgium and Holland.
5. Rhone basin.
6. Rhine basin.
7. Danube basin.
8. Italian peninsula.
9. Algeria and North Africa.
10. Turco-Hellenic peninsula, with Syria.

In the Scandinavian peninsula and Iceland, out of 252 earthquakes recorded, the dates of 214 are known. Of this number 112, (more than half), were during the first half of the present century. Of these 74 occurred in the winter months, (January to March), and 53 in the autumn months, (October to December), while 48 only are recorded in summer, (July to September), and only 39 in spring, (April to June). Thus, while during six warm months the number was 87, during the six winter months the number amounted to 127. The month of January was characterised by 33 shocks, and the month of June by only 10. It has been calculated that the mean direction of propagation is S. 22° 30′ W., which agrees with that of the Scandinavian peninsula.

Within the British Islands the dates of 217 earthquakes are recorded, 108 of them being in the present century. Of these 123 were in the winter months, and only 94 in the summer months. The maximum number (28) was in December. The mean direction was S. 29° 5′ W. to N. 39° 5′ E. Several earthquakes of some magnitude have been felt in the British Islands since 1850, most of them being in winter. A later calculation by Mr. Milne refers to 139 shocks in Scotland and 116 in England. Of these 153 were in winter and 102 in summer months.

In the Spanish peninsula the dates of 201 earthquakes are recorded, 85 of them being in the present century. Of these 114 were in winter and 87 in summer. The mean horizontal direction is E. 31° 56′ S. to W. 31° 56′ N., which agrees well with the recorded direction of shocks. In France, Switzerland, the Rhine Basin, and Belgium, there are 1,369 dated observations. Eight hundred and twenty-six of the shocks were in winter and 543 in summer. The maximum was in December 173 and the minimum in June 77. In the basin of the Danube only 270 dated observations are given; of these 143 were in winter and 127 in summer. In the Italian peninsula, out of 984 earthquakes 531 were in the winter and 453 in the summer months. It is only in the eastern part of the Mediterranean that the recorded facts of earthquakes seem to show a slight preponderance of shocks in summer. Here out of 423 shocks 106 took place in the three winter months, January to March, and 102 in the succeeding spring months. But there are 115 recorded as observed in summer (July to September), and 102 in autumn months. The influence of season here seems to be absent, and the same maximum number (40) is described for January, August, and September, the minimum (30) taking place in the month of April.

If we cross the Atlantic we find in the North American land of the northern hemisphere 134 earthquakes recorded. As to the date of these, 86 took place in winter and 48 in summer. In the Central American district, though known to be very subject to disturbances, there are only 52 earthquakes whose dates are given, but of these 32 occurred in winter and spring, and only 20 in summer and autumn. The totals of winter and autumn are equal to those of spring and summer. In the West Indian Islands, of 690 earthquakes 142 occurred in winter, 156 in spring, 187 in summer, and 154 in autumn; but as the cold is not greater in the winter months, the terms must be understood to mean only the months which, in the temperate zones, are known by those names. The observations, though not very numerous, concerning the dates of earthquakes in Chili and the basin of La Plata, agree with those of the West Indian Islands, and not with those of Europe.

As a general summary of the facts, we may state that of 2,020 earthquakes in Europe, of which at least the season of their occurrence (winter or summer) is known, and of which 1,588 date since the commencement of the last century; 1,163 took place in winter and autumn months, and only 857 in spring and summer. The largest number in a month was 228, in January; the smallest was 126, in May. So far as

Europe is concerned it would also seem, that taken in every way in each separate district, except that of the eastern Mediterranean, and for the last five centuries, there has been a marked and even large predominance of disturbance about the time of the winter solstice, and, as marked a minimum of disturbance at the time of the summer solstice. It may also be estimated from the observations of a period of twenty years of the present century, which there has been nothing to interrupt ready communication and the publication of all extraordinary occurrences, that at least forty earthquakes per annum, or one in every nine days, are felt on the continent of Europe, and the immediately adjacent islands.

An exceedingly important suggestion was made by Professor Perrey in 1853, and reported on by the French Academy in reference to the periodicity of earthquakes, and the connection that may exist between them and the moon's age. From the observations of four years, from 1841 to 1845, very carefully tabulated, he finds that the number of earthquakes occurring near the times of new and full moon are to those at the quarters as 47 : 39. This conclusion cannot be regarded as in any way established; but if it should be so, it points to the influence of currents of earth magnetism in producing earthquakes, or rather, perhaps, in determining the precise date of their occurrence. The whole subject of the periodicity of earthquakes must be considered with reference to this important form of force which, as we know, depends on causes altogether external to the earth, and derived from the sun itself as the centre of our system.

The connection between earthquakes that occur at about the same time in different districts, and the range of earthquakes under extraordinary circumstances are matters that require allusion. Cases sometimes occur in which small earthquakes of the third class are felt in places not a hundred miles apart within a few hours, or two or three days of each other, but between which there appears no relation whatever. Other cases are not rare in which a gentle but continuous tremor affects a whole district, numerous small undulations being so clearly propagated through the earth that the rate of transit of the wave may be calculated. In the years 1841, 1842, (between the 23rd July of the former year and the 8th June of the latter) about 60 small shocks were felt and recorded at Comrie, in Perthshire, Scotland. Of these 12 occurred on 30th July, and the rest were irregularly distributed. Between 1st July, 1842, and that day twelvemonth thirty more shocks were felt at the same spot, and besides them several not inconsiderable disturbances in various parts of England. The most remarkable day was 17th March, 1843, when almost the whole of the western part of England, the Channel Islands, the Isle of Man, the north-east corner of Ireland, and the south-west of Scotland, experienced shocks; but none were felt at Comrie. On the other hand, in 1843, on the 25th August, a severe earthquake was experienced at Comrie, and within an area of more than 100 square miles, with about equal intensity. These are all examples of small vibrations, and generally small vibrations frequently repeated are not very likely to be followed by serious disturbances and earthquakes of the first class. Other instances of long continued slight tremors occurred in 1839 at St. Jean de Maurienne, in Savoy, and at Ragusa, on the coast of Italy, in the years from 1843 to 1850.

Earthquakes that cannot be traced far may, however, be extremely violent, and examples of such convulsions are not uncommon in volcanic districts, after some interruption of volcanic eruptions. Thus, on the 5th February, 1783, a great earthquake was experienced at Calabria, in Sicily, by which the town of Calabria, and about 200 other towns and villages were destroyed, and 100,000 human beings perished. The disturbance, however, was limited to an area of about 600 square miles.* On the other hand, the great and celebrated earthquake of Lisbon, which took place on the 1st November, 1755, was felt throughout an oval area of enormous dimensions, the periphery of the oval reaching westwards in Europe as far as Bohemia, where the hot springs of Töplitz were affected, and northwards to the shores of the Baltic. It traversed the Atlantic, near the Arctic circle, crossing Canada, north of the great lakes, and, coming southwards, included within its area the West Indian Islands, and re-crossed the Atlantic to the northern shores of Africa. An example of very wide area of earthquake action and repeated convulsions occurred in 1835, when several towns were destroyed between Copiapo and Chiloe, on the west coast of South America, and at the same time the island of Juan Fernandez, 365 miles from Chili, was violently shaken. More than 300 shocks were counted in this district between 20th February and 4th March in the year mentioned, and before this the whole coast of Chili had been visited by a most destructive earthquake, felt simultaneously through a space 1,200 miles from north to south.

---

* It is recorded that during this remarkable earthquake the earth was in one particular spot rent by deep chasms, and so violently rocked, that the heads of the largest trees almost touched the ground on either side. Not only was no kind of building able to resist the movement, but tracts of land were actually removed horizontally, so that fields planted with different kinds of corn had exchanged situations. Notwithstanding this extraordinary amount of local disturbance, the towns, even at a comparatively short distance, were not injured, and in the country the shock was scarcely felt. The contrast between this and the Lisbon earthquake, scarcely more severe at any point, is exceedingly remarkable, and probably due to the much smaller depth of the point of paroxysmal disturbance.

The distance between the extreme points affected by an earthquake, and careful observations made at various points as to the amount and direction of the wave, enable the mathematician to estimate within certain limits the probable depth at which the paroxysm originated. That this differs exceedingly in different cases there can be no doubt, but it must be understood that only a very rough approximation can in any case be obtained.

PART THE SIXTH.

LIFE.

CHAPTER XVIII.

THE DISTRIBUTION OF PLANTS IN THE DIFFERENT COUNTRIES OF THE EARTH.

In the introductory chapters of the present volume, vital energy has been alluded to as a form of force. This may have seemed strange to some readers, but it is consistent with all the results of modern enquiry to assume that vitality is one of the many results of the motion that takes place among material atoms. We have seen that force is convertible into heat, or that it may be developed as light, or that it may present itself as chemical action, electricity, or magnetism. Wherever and however it is shown, motion is evidently one of the important properties of matter, and it is, perhaps, indispensable to the very existence of matter in the universe. Matter and motion are ideas which we can hardly dissociate. They belong to each other: with them, we have the world and the material universe; without them, there is simply nothing. If in this sense alone life is indissolubly bound up with the other results of force, it follows that it is one of the forms into which motion, produced in or transmitted through matter, may be modified.

Viewed in this light, it is not difficult to perceive that life in some way may be co-existent with the universe, although the exact form and the conditions in which it exists have admitted of infinite variation. As we recognise a peculiar arrangement of matter, and its distribution into earth, air, and water, so these connect with life and are inseparable from a definite idea of its nature. The conditions of existence at any time are simply the actual conditions of the earth at that time. If they are not fitted for life, there is no life—the forces are otherwise occupied. If they are so fitted, life appears. Life, in this sense, is not an exceptional, but an essential, phenomenon.

There is no special materialism in this view. We say only that life is a part of nature, and that it is a logical and necessary consequence of the existence of a material universe under certain conditions. The mutual relations of matter and motion being once established, they have remained in perfect harmony and system—one series of events naturally growing out of another system. All we say is, that such is the order and law of Creation. Whether it be more reverent to regard life as effected imperfectly by a method of interposition, and by the modification of an incomplete method, imagined in one way and improved from time to time; or whether it be not more to the honour of the Creator to believe that he originally devised a perfect system, that should run its course from beginning to end without interruption,—we must leave our readers to decide. If we can discover traces of a plan that has always developed and will continue to develop perfect results, adapted in every case to such changes as in the full working out of the system must occur, we obtain neither an irreverent nor material view of the Divine mind. We cannot attempt to indicate the working of this plan in all its details, but we may discover and point out certain laws. Among these, the law of distribution of organic beings on the earth is, perhaps, the most important of all. The discovery that such a law exists ought not to be unsatisfactory or painful to any one who seeks merely truth, as it may be learnt by enquiry of Nature.

Vegetable and animal life require that certain portions of the solids, fluids, and gases commonly present in the earth should enter into new combinations and become capable of being reproduced, but always with such small modifications as circumstances may render desirable. They require, also, a constant and large exhibition of force exhibited in motion and heat, and occasionally by light and chemical action. In the more complex forms, electric and magnetic forces are also exhibited. Life is eminently active, compared with inorganic nature, and involves an enormous amount of motion. It endures only for a limited time; but similar forms and combinations, involving similar expenditure of force, grow as it were out of the atoms of a body that is still living. Life is propagated, so far as is known, by germs proceeding from other living bodies.

A certain amount of air and water, and a certain amount of light and heat, are necessary for existence. Thus, there are limits of time and limits of space connected with the distribution of life. Life is most active where there is warmth and sunlight. It dies out quickly at considerable depths beneath the surface of land, and at great heights above the sea. Its simplest combinations are met with where it shows itself under the least favourable conditions. Where the conditions are more favourable, a struggle of different forms for supremacy commences; and by this means the earth always exhibits exactly so much and such kind of life as is best adapted to exist at every point, under the special conditions of climate and circumstances, whatever and wherever these may be.

On the sides of lofty mountains—on the ashes and lava thrown out by volcanoes—on naked rock—and even in the depths of the earth,—there is a tendency for life to step in wherever there may be a place. A minute red fungus shows itself on the surface of snow in the most northern part of the Arctic regions, and claims to be life. A gelatinous mass is separated from the almost boiling water that rises in hot springs from the interior of the earth, and calls itself organic, or the result of life. Life appears at the greatest elevations to which it has been possible to gain access. It has been brought up from the greatest depths of the deepest ocean that have been reached. Every rock, every loose stone, every pool, where there is light, and air and moisture, may become the seat of life. The air carries the germ, or the water conveys it. Whether the original germ of the lowest forms of existence are derivable according to any law that can be discovered from inorganic nature, is still doubtful. But it is certain that all the more complex forms are distinct, and that no one has yet succeeded in obtaining life by artificial means. Neither can we greatly modify the forms of existence, except in a few special cases.

But we know that, according to the operation of some law, or by some interruption of law, changes do take place from time to time. We know, too, that either alteration of structure and modification of specific form, or the introduction of new forms, is effected occasionally, in conformity with some law and co-existent with changes of climate. Thus, whilst in all parts of the world, and through all time, minerals and rocks are reproduced exactly, and have been repeated without change, both plants and animals exhibit adaptation and suffer modification. With regard to organic nature, we have reason to conclude, on the contrary, that each species has its period of life, which must be terminated by death. Just as each succeeding individual of a family preserves many characteristics of its group without absolute identity, so in the case of species there is no absolute and close repetition, but merely a family resemblance. And, just as individuals are born, grow, and die, so do species originate, multiply, and disappear from the face of the earth.

Groups of plants and animals are distributed according to certain laws, both in vertical and horizontal space. Each group tells a history which is of great value, and which forms a chapter in the history of the earth. Where we find identical species spread over a certain area, whether continent or islands, we may be sure there has been at one time free communication, although now mountain chains or ocean depths may intervene and form impassable barriers. Where, on the other hand, in parts of connected land there are distinct groups and representative species doing the same work in nature, there has formerly been geographical separation; and the best adapted species must inevitably succeed, in time, in driving out and destroying the less adapted. This is a great law of nature, and it is one that is the foundation of much valuable generalisation.

It has been found convenient to group plants into three principal classes, which differ much in their structure and mode of growth. They are (1) the *Cryptogamia*, whose flowers and seeds are too minute to be seen, or are hidden in some unusual part of the plant. Such is the case with fungi, many sea weeds and lichens, mosses, and even ferns. They have, in some respects, a more simple structure than the other plants. They are the forms of life that appear under the least favourable circumstances. They range more widely, and they vary less under great changes of condition. They endure through longer time, and range over larger space. They are marvellously abundant, spreading everywhere, no one knows how. They start into life even when every chance of successful growth seems absent. Their seeds are always at hand, in the air and water as well as on or within the earth.

Next come (2), the *Monocotyledons*, or plants that grow from simply formed seeds, ripened after the plant has flowered.

The seeds are like those of the various grasses and corn, the young plant commencing life as one little leaf wound spirally outside the seed. It is continually followed during life by other leaves, and the outer case of dead leaves left behind becomes ultimately a woody stem, while the growth continues, and the plant may ultimately become a tree. Palm-trees are good examples of this mode of growth on a large scale—all the grasses are illustrations on a small scale.

(3). The *Dicotyledons* form a third division. As the structure of monocotyledons is more complex than that of cryptogams, so that of dicotyledons is more complex still. In them a double seed gives off two leaves, diverging as they rise, and allowing a woody stem to come up between them. From time to time branches are given off in the same way. In the larger plants of this kind a growth takes place outside a central axis, the external coat of bark being the most essential part. In larger plants—as shrubs and trees—the trunk increases by successive rings, which mark the years of its existence. A circulation of sap or juice keeps up a perpetual life through trunk, branches and leaves; leaves at a certain period of the year develope into flowers, and these again into fruits, and from each fruit, if placed under favourable conditions, another growth takes place of the same kind, and a new plant is produced. For years, centuries, and even in some cases thousands of years, the growth continues, and the original structure remains. Year after year sees a production and decay of the leaves and the flowers, but the fruit cast into the ground preserves the identity of species as long as the circumstances are more favourable for the growth of that plant than any other. With many of these plants, however, the time of existence of the individual is limited to one season. The seed developes rapidly into stem, and branches, and leaves,—the bud forms, the flower appears and decays, the fruit follows, ripens, and is dispersed, and then the plant dies. Such plants are called annuals. In temperate latitudes one-sixth part of the total number of species of the two more complex forms of plant life are annuals—in the tropics not more than one in twenty, and within the Arctic and Antarctic circles only one in thirty. Plants that form a solid woody stem are more numerous near the equator; grasses and such-like plants are more common in the temperate zones, while mosses and lichens abound in high latitudes, or at high elevations. There are, however, important exceptions to this distribution, especially with regard to the ferns and other higher forms of cryptogams.

The distribution of plants being dependent on favourable conditions, we must know accurately what the conditions are, if we would understand the nature of the group likely to be found in any given place. There are certain parts of the earth—as Equatorial America—that seem especially adapted for forest vegetation; certain others—as the islands of the South Seas—where ferns chiefly inhabit; and others, where lichens and mosses are most common. The causes are for the most part climatal, though soil has much to do with the determination of the tribes that shall flourish in any district at a given time.

But climate does not depend entirely on latitude, and thus the distribution of plants is not confined to definite horizontal tracts in similar geographical position. Although, generally speaking, the climatal conditions are similar in places similarly situated, this is only the case where there is no great difference of level. On the sides of high mountains within the tropics we may find every variety of temperature, from the hottest and most humid atmosphere to a thin, cold, dry air, like that within the Arctic circle, and quite as cold. We have thus certain limits of vegetation in vertical as well as horizontal space. Warmth and moisture are conditions eminently favourable to plant life, and all organic nature is chiefly energetic where these abound, provided there is no interference of interests. But where there is such interference, whatever be the cause, the species best adapted to the conditions must gain the day in the great struggle. Sometimes vegetation advances at the expense of animal life, but elsewhere animal life prevails almost to the exclusion of vegetation. The banks of tropical rivers at low level are examples of the former, and the waters of the ocean of the latter case. Certain kinds of vegetation under certain circumstances will often permanently exclude other kinds.

There are a number of recognised botanical regions in the earth. The number of these regions is large, and not absolutely defined, as botanical authors increase them from time to time, according to the progress of discovery. It is neither necessary nor desirable to trouble the reader with detailed accounts, or mere lists of these, the object of the present chapter being rather to give a general idea than teach the special facts on which the conclusions are based. But it will be useful and suggestive to place before the student the outlines of a compact and concise arrangement long ago suggested by Humboldt.

It is assumed in this outline that there are parts of the earth where certain tribes of plants are most at home. Here they overpower all intruders. Hence they are believed to have diverged, entering occasionally adjoining territories, but not conquering them. Each group is supposed to have a place, and for the present each keeps it. How long they have done so, or when their empire will cease, we must not now consider. The former inquiry belongs to palæontology, or the history of past races, the latter is purely speculative.

At present, then, we may say, speaking of lands near the sea level, that (1), palms and bananas are the plants of the equator, up to 2,000 feet; (2), tree ferns and species of *ficus* belong to the tropics generally, corresponding in height at the equator to between 2,000 and 4,000 feet; (3), myrtles and laurels to sub-tropical regions (4,000 to 6,000 feet); (4), evergreen trees to warm temperate countries (6,000 to 8,000 feet); 5), deciduous trees, such as the oak and beech, and most of the north European forest trees, to the colder temperate zone (8,000 to 10,000 feet); (6), pines to the sub-arctic zone (10,500 to 11,500 feet); (7), rhododendrons to Arctic latitudes or high elevations (11,500 to 13,500 feet); and lastly, (8), the lichens and mosses, and what are sometimes called Alpine plants, are chiefly met with on the lands around the two poles, or on the highest points of land at which vegetation appears in lofty mountains (between 13,500 and 15,500 feet at the equator).

That this distribution represents important and intelligible facts no one will deny, and it will be evident that the law of distribution is applicable, without much difficulty or error, in the case of mountains of great elevation under the tropics. On the mountains of Mexico, where the palm flourishes at the foot, the last trees are met with at a height of 13,000 feet. Above them are Alpine plants and lichens. On the Himalaya mountains the birch is found on the north side at 14,000 feet, and the Alpine plants reach much higher.

Although there is a general correspondence there are causes which produce a marked difference of range in different parts of the world. Thus the pine, so abundant and characteristic in most parts of the world, and so well defined in its habits, only reaches to 10,870 feet in the Pyrenees and 6,700 feet in the Alps. In Lapland neither the pine nor the birch rise to 2,000 feet above the sea. So, again, the rhododendron is found as the last of the shrubs, attaining in the Caucasus 8,800 feet, in the Pyrenees 8,300 feet, in the Alps 7,480 feet, and in Lapland 3,000 feet.

One of the most instructive facts with regard to the distribution of plants is, that in different botanical regions, whether of vertical or horizontal space, it is usual to find the species so far alike that when carefully compared, and even recognised as performing the same part in nature, they are frequently not identical. This is expressed by naturalists, when they speak of such species as *representative.* In similar climates in the opposite hemispheres, where there can have been no communication, because of the intermediate belt of tropical climate, this peculiarity is best seen and most readily admitted. No doubt it is possible that even Arctic species, gradually rising from the level of the sea to elevations where their own climate prevails, may travel from the north to the south pole, availing themselves of the great meridional chain of the Andes and Rocky Mountains. In this way some species obtain a wide range. But it is clear that this must be exceptional, and that generally there will be no such transmission. Under ordinary circumstances different countries have a distinct flora. Must we then assume that at each spot which seems to be the metropolis of a natural group there was a special creation, or should we not rather assume that there exists a power of adaptation and modification—some great natural law, whose operation is to develope new forms from old species from time to time, whenever circumstances call for them? This is a question not less interesting to the physical geographer than to the botanist. It must, however, be remembered that there is really identity in some very distant groups of plants. In these cases geological conclusions may sometimes point to the true cause—namely, a great alteration of level since the species was originally introduced. They may thus have migrated, though now such a mode of transmitting identity of species would be quite impossible, since communication is altogether cut off. Thus the flora, or natural group of indigenous plants, now characteristic of Tierra del Fuego, is the same as that of the Chilian Andes, and as the islands may formerly have been part of the main land, the transmission is possible.

There is no doubt that some plants are more hardy than others, and more capable of adapting themselves to change of climate. Such plants will certainly migrate much farther than species less capable of modification. They may even, sometimes, actually displace the indigens. There seem to be a few plants common to England and Australia, and others common to northern Europe and North America; and the existence of these, at points so distant, can only be explained by the extreme hardiness of such plants, and their resistance to extinction. It is said that in the Falkland Islands there are thirty or forty plants, of species identical with those natural to Great Britain. It is chiefly the lichens and other simpler forms of vegetation that range thus widely; and, indeed, almost all the lichens brought from the southern hemisphere have been identified with northern species. At any rate, the fact of identity of species in distant countries where communication is now impossible, is very important and suggestive.

To come now to the actual floras of different regions, we may begin with those of the equator, and the portions of the tropics immediately adjoining. Several groups, marked with tolerable clearness, may be quoted, and briefly alluded to.

The great Archipelago of the eastern seas (the Indo-Australian archipelago of Mr. Wallace) is a district perhaps the most remarkable in the world for its active volcanoes, and for proofs of enormous recent change of level. It is a good starting point for the physical geographer, as one portion connects itself with Asia, and another portion with Australia, and although at first view, all these islands have the appearance of a natural group, they are really very distinct, and separated by a broad line of demarcation.

On the Asiatic or western side of this archipelago, there is much that is interesting and curious in the flora, although most of the species are identical with those in northern India. On the other side, towards Australia, there are species common throughout all the lands to the east and south, including Australia itself. The Indo-Malayan, or westward botanic region, includes magnificent palms, zamias, cycads, bamboos, a singular myrtle, a mimosa, the teak tree, and many other less known trees, all characteristic of tropical vegetation. Orchidaceous plants and tree ferns are also exceedingly abundant. No countries are richer in fruits, and many of these are of extraordinary flavour. Java is perhaps the richest of all. In it, and others of the group, are thickets of screw-pine; the camphor-tree, in whose stems solid lumps of camphor are found; a variety of myrtle, whose buds are picked and exported as cloves; laurels yielding cinnamon and cassia, and many kinds of pepper, all requiring intense heat. The caoutchouc and gutta-percha trees are also abundant, and the nettles are stimulated and developed into the upas-tree, one of the most deadly of vegetable poisons. Many of the fig-trees have juices so acrid as to remove the skin. No country is richer in club mosses, and none presents a more dense forest, where an undergrowth of gigantic grasses is met by a mass of orchidaceous creepers and air plants, climbing over the tops of the lofty trees. No less than three hundred orchids and two hundred club mosses have been described from Java, and most of them are peculiar to that island. Separated by a channel of deep sea, not fifteen miles wide, we have a region of a totally different character, in which the vegetable life resembles that of Australia.

Not very dissimilar to the Indo-Malay Archipelago, and with many identical species, we find the flora of the plains of Hindostan. This region extends from the valley of the Ganges to Cape Comorin. Although much of India is on the verge of the tropics, or even beyond them, the climate is tropical, and tropical species range widely and uninterruptedly. The Indian cotton tree, some of the fig-trees, the dragon's wood tree, the ebony tree, and the gigantic banyan, the palms, the trees yielding ginger, tree-ferns, numerous trees yielding dye woods, the varieties of the orange, (almost all natives of India) innumerable parasites, and a multitude of highly-scented flowering shrubs, are all found there, and many of them have been for centuries introduced to other and distant countries, where they have taken such deep root as to have become regarded as natives, and where they have often driven out the real indigens. As an instance of the luxuriance of growth of some of these trees, it may be worth while to mention the fact that several millions of cocoa nuts have been exported, in one year, from the island of Ceylon alone. It would be impossible, in the limits here assigned, to mention, however briefly, all the important plants and trees met with in this marvellously rich metropolis of certain tribes of the vegetable kingdom.

Only less varied, if not equally rich in its flora, are the banks of the gigantic rivers of tropical South America. There, on the Amazons and in Brazil, are also seen endless contrasts of form, endless varieties of colour, and peculiarities of growth almost amounting to anomalies. The largest trees bear brilliant scarlet, purple, rose coloured, blue, and rich yellow flowers, blended with every conceivable shade of green. The acacia is represented in many varieties, and lofty reeds and grasses are mixed with a multitude of creepers, air plants, and orchids, bright with the most vivid colours. Five hundred species of palms (half the total number of described species), bignonias, with their huge trumpet-shaped flowers, coffee trees of many kinds, and the majestic bombyx, (silk-cotton tree) are mixed in strange confusion.

But although there are many points of resemblance between the tropical vegetation of the east and west, there is hardly any identity of species. What is sometimes called the *facies* —the general aspect—of the vegetation, is also exceedingly different. Each is glorious and beautiful in the highest degree, but the style is different. Nature has developed differently under the different skies, and for some reason, whose wide action marks it as in a high degree important, the contrasts are more striking than the resemblances, even when the fact of representation of the species is most evident, and the conditions of existence seem to us the most similar.

Africa also has a tropical flora of its own, but it is both less known by accurate botanical description, and apparently less strongly marked. African explorers have rarely been technical botanists, and the few physiological botanists who have been great travellers, have not yet discovered the treasures that must exist in the lands recently visited and approached near the equator. More is known of the west than of the east coast. Most of the tracts yet visited on the east side, and richest in peculiar forms, have been too much above the level of the sea to allow of a growth of tropical vegetation, that should compare with that of India, the Indian Archipelago, or Brazil.

It would seem that the plants of the east and west sides of equatorial Africa are really distinct. On the eastern side, where Africa touches Arabia, the flora of the coast is common to the two countries. The Euphorbia tribe, however, is essentially African, and forms a connecting link. The varieties are many; but they are not generally handsome plants. On the west coast is found the *baobab* (Adansonia) of Senegal, the circumference of whose stem is sometimes double the height of the tree. We have also the *Pandanus candelabrum*, rising solitary on the plains, with its long, forked branches and stiff leaves; the palm oil tree on the coast, and the mangrove in the water. These, if not indigenous, are now predominant and characteristic.

Tropical Arabia is as remarkable for its balsams and richly-scented gums, as the islands of the Indian Archipelago for spices, and South America for its gorgeous colours. Coffee, now best cultivated there, is believed to have come from Ethiopia; but the figs, mimosas and date palms of Arabia are its own. The extreme dryness and great heat of the climate appear favourable for the development of those essential oils that abound in the odoriferous plants and flowers of this part of the tropics.

Out of the tropics, both northern and southern Africa are rich in peculiar forms of vegetation. Towards Europe, indeed, the vegetation north of the desert is nearly identical with that of the Mediterranean. Towards the equator, the tropical character is soon recognised. On the south side of the equator, the interior of Africa is less crowded with large vegetation than the south temperate regions of South America. Almost all the plants, also, are highly characteristic. With a poor soil, dried up and burnt for a large part of the year, the heaths and those plants called by botanists *Protea*, are exceedingly varied. The Euphorbiæ, also, are present in great strength. These succulent plants, growing into trees forty feet high, often of the strangest form and shaped like a vast candelabrum, are entirely without leaves, and are covered with prickles. The Zamia, another strange and representative form, is also common. The Euphorbiæ represent the cactus tribe, and the zamia the cycads, but they are quite distinct in botanical character. The thorned acacias are also common in this district.

Australia, like South Africa, exhibits highly characteristic forms of vegetation. The gum trees (*Eucalyptus*) and leafless acacias are examples. Even the former are dull and gloomy forms of vegetation, while the latter are wintry and forbidding in the extreme. The leaves of the forest trees are generally of a dark olive green; and it is only in the northern part, close to or within the tropics, that the character of the vegetation improves.

It must not, however, be supposed that there is no beauty in the Australian forests. The trees are often rich in colour and varied in form, but they are always peculiar, and very distinct in all essentials from those of South Africa. Norfolk Island, not far from Australia, is the home of the ferns. On the other hand, only one species of tree fern is found in Tasmania, although the distance is so short that the islands of New Zealand and Tasmania might reasonably be supposed to have had a common origin. New Zealand, exceedingly rich in the Coniferæ, or pines, is also well supplied with species of plants not elsewhere known. The vegetation in that country affords a multitude of forest trees, but none that can be regarded as representing either the oak, the birch, or the willow. And yet New Zealand is nearly the antipodes to England.

The forests on the banks of the South American rivers away from the tropics are almost as varied and beautiful as those close to the equator, and contain many noble trees not elsewhere found, but affording admirable timber and delicious fruit: the palm and cinchona (yielding Peruvian bark) abound, and the algaroba, a kind of acacia, yields a bean used by the Indians both for bread and to make a strong fermented liquor. The aloe and the cactus abound, especially towards the mountains. From the former is obtained a valuable fibre. The cochineal insect feeds on the latter. Those gigantic pines, the *Araucaria imbricata,* of Brazil, and *Araucaria excelsa*. of Norfolk Island, so like and yet so different, represent the effect of climate in developing analagous forms, under circumstances not very dissimilar.

The vegetation of North America in the north temperate zone may conveniently be compared with that of Europe in similar latitudes. There is a certain resemblance, but each has a distinctive character. Owing to the presence of lofty mountain chains running from north to south, the plants adapted to the colder regions of the north are found at gradually increasing elevations, till we reach Mexico; but for the same reason there is a marked difference between the floras of the eastern and western divisions of the country. Even on the two sides of the Alleghany mountains this difference has been observed; but the plains west of the Rocky mountains exhibit in a more marked manner a vegetation of their own, and are distinct from the floras of the central plains on the eastern shores.

But the flora of the middle states of North America, in a latitude nearly the same as that of a large part of southern Europe, exhibits very striking peculiarities. The evergreen pines, the scarlet oak, the yellow beech, and the purple nyssa, produce in autumn the most marvellous effects of colour; and under the bright sky that prevails on the Atlantic shores they are brilliant to an extent hardly conceivable by the inhabitants of our cloudy atmosphere. In these cases, however, the analogy is great, and many of the trees belong not only to the same natural groups, but are species closely allied to those of Europe. Others, as the magnolia, the tulip trees, and the hibiscus, characteristic of North America from Virginia to the Gulf of Mexico, are familiar to us, as having been introduced successfully into Europe, but can hardly be said to flourish in the Old World. But, notwithstanding this, the *facies* of vegetation on the two sides of the Atlantic is quite distinct. Largeness of dimensions is characteristic of the American as compared with the European trees. The Canada poplar, the American chestnut, the American sycamore, the black walnut, and the hiccory,—and in the southern States the pitch pine and the cypress, with a rich under-growth of rhododendrons, azaleas, and many herbaceous and climbing plants, are illustrations of this fact, and of the nature of the difference exhibited.

There are in North America two wooded regions, separated by vast prairies, where grasses and herbaceous plants predominate. Magnificent pines and many other timber trees are met with on the Pacific shores, and these are distinct from the species in the east. Mexico and Central America combine to some extent the vegetation of North and South America, though approaching the latter more nearly. On the higher grounds oaks, chestnuts and pines abound; and on the plains there are palms, logwood, mahogany, and other equally characteristic trees. There is also a rich vegetation of smaller plants, of which the various pepper trees, the passion-flower group, the pine apple, the tobacco plant, the indigo tree, the yucca and aloe, and the yam, are familiar. Species of the cactus tribe range widely through the whole country, and the Indian corn or maize is believed to be indigenous. The sugar cane is and has been from time immemorial common to both the eastern and western tropics, and has also a wide range.

It is impossible to specify all the peculiar and familiar plants of these wide tracts; but it will be evident, even from these brief references, that the general law alluded to holds good in all these extreme cases. Wherever there is a broad, natural separation, either by deep sea or lofty mountain range, that has endured for a long period, the vegetation on the two sides of the barrier is so far distinct as to justify the conclusion that has been suggested. Islands, for the most part, partake of the character of the adjacent main lands; but where this is not the case, a good reason can generally be assigned. Thus, the vegetation of Madagascar is to a great extent peculiar to that island, and has more in common with the Mauritius and the Isle of Bourbon than with India or Africa. The Seychelles islands, ten degrees north of Madagascar, have a remarkable palm of their own. The Sandwich group and other islands in the Pacific, with the other islands of that vast archipelago, form parts of a great natural province, very distinct from any other; and the Galapagos Archipelago, entirely volcanic, has a peculiar flora. Although under the equator, and not lofty, these islands more resemble in their vegetation the cooler parts of South America than any land in a similar latitude to their own.

As the Rocky Mountains of North America, so the Andes in South America form a great natural barrier, across which there is little or no emigration of plants. No doubt an extreme difference of climate has much to do with this, but the fact is remarkable. On the western side of the Andes, on the coast of Chili, and far down into the south temperate zone, the vegetation has a singularly tropical character, though the climate is more excessive than in corresponding latitudes in the north temperate zone. This is the case at considerable heights in the Andes of Chili and in other parts of the same great chain.

Extreme humidity and a very equable climate are characteristic of the islands in high southerly latitudes, and the vegetation corresponds with this condition. A peculiar evergreen beech, and another well-marked species, range very far. A hardy arbutus accompanies them, and, with certain flowering plants, these extend into the region of Alpine plants, mosses, and lichens. Generally, it has been remarked that the floras of most of the groups of islands near the Antarctic Circle, far removed from each other in longitude, are much more similar than is the case in corresponding latitudes in the northern hemisphere, even though the lands are there connected much more closely.

We come, lastly, to the distribution of plants in the temperate regions of the Old World and in the Arctic Circle—countries varying much in climate, but separated only slightly by mountain ridges of small elevation, since the great mountain chains range nearly parallel to the equator, and thus do not interrupt the passage of species over the continuous land stretching uninterruptedly from west to east. On the other hand, there are sufficient breaks in the mountain chains to allow of a considerable migration from north to south.

Even within the British Islands there are no less than five botanical districts, indicating many migrations that have taken place when our islands were connected geographically, and by land, with parts of Europe from which they are now quite separated. Thus the flora of the west and south-west of Ireland is like that of the south of Spain, the less hardy plants being absent. The south of England and Ireland resembles the Channel Islands—the south-west of England, Normandy and Brittany—the tops of the Scottish hills agree with Scandinavia, and much of the middle of England shows a near resemblance to Germany. Three thousand species of plants have been collected, and now live together in a certain degree of harmony, in the small compass of England, Wales, Scotland and Ireland; but to understand the relations of these it is necessary to travel far and make much careful comparison. In a word, the British Islands have not always been independent of the main land of Europe—they have had the opportunity of receiving many series of plants one after another—they have selected from each that which was best adapted to the peculiarities of position and climate, and yet, in spite of all struggle and all admixture, it is not difficult for the botanist to point to the original source and metropolis of each. The plains towards the Atlantic and the hills and mountain sides with similar exposure are very different in essential points from the mountains of Wales and Scotland, and the hills of England. So, also, the chalk of the south-east of England is distinct from the oolitic district, and this, again, from the new red sandstone. The carboniferous limestone and the coal measures—the old red sandstone and the silurian rocks, all exhibit peculiarities, and show, in a marked manner, both the elasticity and the rigidity of the laws that govern the distribution of plants on the earth.

Central Europe is chiefly characterised by deciduous trees—trees whose leaves fall at the commencement of winter. Oaks, elms, beech, ash, maple, lime, alder, sycamore, larch, fir, yew and pine are the prevailing species, and they are accompanied by a moderate undergrowth of wild apple, wild cherry, holly, hawthorn, broom, furze, wild rose, honeysuckle, clematis. In the open ground we find carrot and anise—the family containing lettuce, endive, &c., and that of which the turnip, cabbage and cress, the wall-flower and the stock are familiar examples. These latter are eminently characteristic of middle Europe, and they are almost confined to the northern hemisphere. They occupy the plains and low-lands, and occasionally the plateaux. The mountain sides and tops are Arctic in their vegetation. The grasses include wheat, and towards the northern extremity, barley and oats.

South of the mountain chain we find numerous evergreens—trees which only part with the leaves of one season when they are driven off by those of the next. The ilex and cork oak, the cypress, the hornbeam, the sweet chestnut, the laurel and laurustinus, the carob and juniper, the arbutus and myrtle, the jasmine, and many kinds of pine, especially the *Pinus maritima*, and the stone pine (*P. pinea*), are characteristic in a high degree. Aromatic herbs and beautiful flowering plants are here indigenous. The anemone and tulip, the mignonette, narcissus, gladiolus, lilies of many kinds, and the carnation, though flourishing by careful cultivation further north, are here native. The balsams, the oleander, some palms, grasses bearing millet and maize, many large sedges, the aloe and the cactus, also take their place on the shores of the Mediterranean, while the grape-vine, the olive, and the orange and lemon flourish almost as freely as in their native habitats.

As we advance eastwards, however, the conditions of climate change, and the characteristic vegetation changes also. Syria and Asia Minor are common ground, and partake both of the east and west. The almond, the oleander and the locust tree are derived hence; the walnut, peach, melon and cucumber, and some of the many ranunculi, come from Persia; the date palm, fig, olive, vine and apricot are believed to have been introduced from Armenia; while on the Black Sea we have species of rhododendron and azalea from the Himalayas.

The rich valleys, opening out from the lofty mountains, in warm temperate latitudes of western Asia, yield the oriental plane, many odoriferous shrubs, acacias, mimosas, the jujube and the tamarisk. In spring they are covered with clover, thyme and violets. The steppes a little to the north are also clothed with innumerable flowers and grasses in spring, and when attended to yield incredibly large crops of wheat, without other cultivation than an occasional fallow.

The deserts on the northern side of the mountain chain of central Asia are dry and burnt, but they afford food for numerous herds. They separate the flora of western from that of eastern Asia, as exhibited in China and in the Japanese Islands. The tea plant is one of the most important of the cultivated plants of the Chinese flora. It is a hardy species of camellia, and is associated with many shrubs, not ranging widely, though capable of being cultivated in other countries. With a certain resemblance in climate, there is a very marked and important difference between the flora of the Pacific and that of the Atlantic coast of the Old World, in similar latitudes.

Very wide tracts of northern Asia, and some parts of the extreme north of Europe, are characterised by Arctic vegetation. The pine, the birch and the willow here replace the oak, the beech and other forest trees; poplars, elms, and the Siberian pine are equally different and equally characteristic. The black birch is associated with rhododendrons, and each terrace of the mountain chains, or each parallel of latitude, exhibits in its flora the amount of its departure from the temperate zone. Most of the species are distinct, even where the resemblance is sufficient to have given to the food and other plants the same names as those by which the corresponding species are known in other lands. Wheat, barley and buckwheat, and further north, or at a higher level, oats, are also grown, but they have been introduced. Only a remarkable grass and a few stunted forest trees are indigenous. Most of the food plants have been reduced to their present condition as cultivated varieties from time immemorial.

Still further north the vegetation is altogether stunted and trees disappear. The gentian, certain kinds of stonecrops, and a kind of pansy still remain, but these, also, give way before long to lichens; the last remains, as the first commencement, of vegetable life. The woody plants have now disappeared entirely, and there are left, at the most, a few plants not rising more than two or three inches from the ground.

In all these different places, then, and at all elevations, there are certain tracts of land in which certain plants occupy the principal space. They may and do extend beyond, but in that case they cease to be representative and characteristic. Other kinds come in and perform the same part in nature, destroying or obscuring the types where they meet on neutral ground, but very often representing very closely the species existing under similar circumstances elsewhere. There are, doubtless, some few species of almost universal range, as there are others limited to an exceedingly small area, but for the most part the range is kept within definite limits.

There is an important vegetable growth in the sea, different in many respects from that belonging to the land, though there are certain land plants, such as the mangrove, that can exist permanently in salt water. The marine plants, commonly so called, are of two kinds, one jointed and thread-like, of which the confervæ are examples, and the other leafy, glutinous and sometimes woody. They are often attached to stones, but many kinds are provided with air bubbles to float them, and exist permanently on the surface. The remarkable appearance of the Sargasso Sea in the Atlantic is due to the presence of an incredible quantity of this second kind of weed. Certain of the marine plants are flower-bearing, but these are very limited in their range, and are confined to coast lines. Most of them are cryptogamic, and some of them range very widely.

Dr. Hooker has distinguished ten provinces possessing marked peculiarities of marine vegetation. There are also provinces of depth; but these are less known, and apparently less important, though varieties of colour and growth are very marked. Eight marine provinces have been described. These are—(1.) The Northern Ocean, near the Pole, where there are numerous forms of very simple structure, incredibly abundant under certain circumstances, and ranging to great depth. (2). The North Atlantic, where several species of *fucus* are characteristic. (3). The Mediterranean, where the water is warmer and the growth very distinct. (4). The tropical Atlantic, where the sargassum or gulf-weed is found, with many others. (5). The Antarctic region is also peculiar, and contains many special forms of enormous dimensions, forming submarine forests of tangled weed, sometimes 300 feet long, growing off Patagonia, on the western coast of South America, and among the Falkland Islands. (6). The Australian and New Zealand region is quite distinct. It includes many British species. (7). The Indian Ocean and Red Sea; and (8), the Japan and China Seas.

The larger and more highly organised forms of marine plants are for the most part widely spread and easily recognised; but there is not unfrequently to be recognised on water a dull filmy appearance, or brown stain; and this being examined, is found to consist of small groups of cells which multiply with a marvellous rapidity. Each one of these obtains from sea water minute particles of flint, which are deposited in plates covered with lines, and marked with the most elegant patterns. The cells themselves, being simple vegetable productions, decay almost as rapidly as they form, but the atoms of flint within which each is enclosed are permanent, and sink down in time to the bottom of the sea. To such an extent do they multiply that in the South Pacific Ocean there is one heap which covers a space 400 miles long and 120 miles broad: the thickness being great and rapidly increasing. Elsewhere similar rapid accumulations are being made by means apparently not less inadequate. Thus the Red Sea and Indian Ocean abound with a conferva resembling chopped hay, which is found also in the Atlantic, off the shores of Brazil. The Japan and China Seas exhibit other peculiarities, and belong to a distinct region.

It is clear, then, that a general resemblance in the conditions of existence in different parts of the world does not involve identity of vegetable species, for in many cases where the climate is equally favourable in distant spots the species are not the same. Thus, in South Africa, New Zealand, Australia, and South America, we have four large and important districts not very dissimilar in climate, and all certainly capable of similar growth within certain limits. There are other districts north of the equator that might well compare with these in point of climate, but if we limit the comparison to those on the same side, we still find only representative species—hardly any that are identical. On the other hand, we may introduce the heaths of South Africa into Europe with success, just as we can cultivate the potato and grow excellent tobacco. It is certain that species introduced artificially may be quite as well adapted to the climate and soil of a country as if they had grown there naturally, and it is impossible not to repeat the inquiry already so often suggested; namely, why it is that so marked a difference should exist in the natural productions of similar climates in different parts of the world?

The view that from time to time new centres of creation have been formed, and sets of plants introduced of species entirely new, is that which till lately has been most usually adopted by naturalists. It has seemed to agree with the idea that, from time to time there have been great geological changes, acting so widely, and in a manner so complete, as to alter entirely the general face of the earth, and start as it were from a fresh point. This view is not supported by modern discoveries in science. There is no proof of any such convulsive movements involving universal destruction. Neither is there proof of any corresponding destruction of species. That new forms have occasionally been introduced, adapted to changed conditions, is certain. How or when they have been produced is still a mystery. We must return to this subject after considering the distribution of animals, and the history of species in time as well as space.

CHAPTER XIX.

THE DISTRIBUTION OF ANIMALS ON THE EARTH.

The distribution of groups of species of animals on the earth, and the limitation of certain species to definite areas, is not less distinctly traceable as a great law of nature than the distribution of plants in distinct regions. In the case of animals, no doubt there is on the whole both a greater power of locomotion and a greater power of adaptation than in most plants. Even the animals that appear most fixed, as those inhabiting shells, have in many cases ample power of migration at some period of their existence, while certain tribes—as fishes and birds—would seem able, if they desired, to find convenient habitats in all parts of the element to which they belong. But in spite of this there is the same general grouping observable. Species appear to have originated in certain centres. From these they have extended, but they have not, as a general rule, reached beyond a certain point. There is a kind of magic circle from which they do not naturally escape, although if they are once removed from the influence of the spell they sometimes not only exist and flourish, but even destroy the indigenous species.

The case of the horse affords a good illustration of this fact. It is certain that the native home of the horse is in the vast plains of western Asia. The breed now running over the boundless plains of South America was introduced into that country by the Spaniards only a few centuries ago. But this breed is now wild, and has completely taken possession of the country, thrusting out other animals that once inhabited the South American plains. So in Australia, the dog introduced by the English will certainly before long drive out and destroy the Australian dog; and the whole marsupial tribe, once the prevailing type in Australia, will soon become extinct. In civilized countries the wild animals die off by degrees, and thus the wolf and the beaver have left England, and many feline species are driven out of Europe. Some animals, such as the dodo, common a few centuries ago in the island of Bourbon, have become extinct, and no living individual seems left to gratify our curiosity. It has often been observed that the rat indigenous to England, has been driven out by the more vigorous species of the same animal that has come over from northern Germany. Many other examples might easily be found illustrating the same fact, and showing that what may happen when species are artificially introduced by man does not happen in a state of nature.

At the same time, it must not be forgotten that the introduction of man was a part of the great plan of nature, and therefore that all the modifications he has effected are in all probability nothing else than useful and suggestive illustrations of what is done to a greater or less extent by all species. The introduction of man on the earth, and even the civilisation of certain races, to some extent, is now known to date very far back in the history of the world.

No doubt it is a principle or law of nature that the method adopted in providing inhabitants for any district involves a special adaptation to the peculiar conditions of the district, especially its position, its elevation, its climate, rain-fall, and soil. But even when there is a marked and close resemblance in these respects in distant lands there is no absolute repetition of identical species. Some essential difference is almost invariably traceable, although, perhaps, there may be a very close external resemblance in addition to identity of habit. Such is the case in a very marked degree with the inhabitants of the land, both in horizontal and vertical space.

A precisely similar method or law may be enunciated in reference to the distribution of marine animals. Regions of depth correspond with zones of elevation, the inhabitants being affected by the rock bottom much as the dwellers on land are by the soil. So clearly defined are these regions that in a particular part of the Mediterranean, between Greece and Asia Minor, where the facts were carefully observed some years ago by the late Professor E. Forbes, we find it remarked, that "certain species in each are found in no other, and several are found in one region which do not range into the next above, whilst they extend to that below, or *vice versâ*. Certain species have their maximum of development in each zone, being most prolific in individuals in that zone in which is their maximum, and of which they may be regarded as especially characteristic. Mingled with the true natives of every zone are stragglers, owing their presence to the action of the secondary influences which modify distribution. Each zone is capable of subdivision into smaller belts, distinguished for the most part by negative characters derived from the cessation of species."*

The animal kingdom is distributed partly in the water, partly on the surface of the earth, and partly in the air. In illustrating their distribution, it is convenient to consider the inhabitants of these different parts of the earth separately; and we may conveniently begin by an account of those met with chiefly in the water.

The inhabitants of the sea are varied and multiplied to an extent often little appreciated. All classes of animals there find representatives, and some are almost or entirely confined to water as the element in which they live and breathe. Of the mammals, or sucking animals,—the quadrupeds of every-day life—there are numerous examples, not less remarkable for their vast proportions than for their usefulness to man. The whales of all kinds haunt the open ocean, some of them being the largest animals in creation. The common whalebone whale, sixty feet long, and whose head alone measures twenty feet in length, weighs not less than seventy tons when in condition. This animal is unable to take within its capacious jaws any substance except the most minute and soft animal matter, and feeds on food apparently quite inadequate to sustain such gigantic life. Other whales are still larger and yet more strangely proportioned, and are supplied with different food, generally, however, cuttle-fish and other small animals. All kinds are capable of extremely rapid motion through the water, and are admirably adapted to the element they inhabit.

Other large and cumbrous animals, suckling their young and provided with at least the rudiments of arms and legs, though externally fish-like, are often met with in high latitudes, and occasionally characterise even tropical seas. Some of these, such as the seal and walrus, are quite distinct from the whales, while others approach the latter far more nearly in their structure. The dugong and the manatee are of this kind, and from their occasional habit of swimming with their calf-like heads out of the water, they have given rise to a large class of stories of fabulous animals, of which the mermaid and perhaps the great sea-serpent may serve as illustrations. The larger seals, as well as these sea-cows (as the manatee is called), yield much valuable oil, and are killed off very rapidly for this purpose. More than three millions of seals are reported to have been taken on one group of islands in Behring's Straits in the fifty years terminating in 1833. The walrus is a fiercer animal than the seal, and not unfrequently attacks its human enemies. The white or polar bear and the sea otter may also be regarded as marine animals, since they live almost entirely on or under the ice, where they obtain their food, rarely approaching land.

---

* E. Forbes. Report of Ægean Invertebrata. Brit. Assoc. Rep., 1843, p. 155.

The birds that belong to the sea are very curious, and their numbers beyond all calculation. Every naked rock or surf-beaten cliff that rises over the immeasurable deserts of ocean, is the refuge of myriads of sea-birds; every coast, from the poles to the equator, is covered with their legions, and far from the land their swarms hover over the solitudes of the deep.

The penguins are, perhaps, of all others the birds that most widely depart from the ordinary type of their class. Their wings are adapted exclusively for motion in water, and they swim with such rapidity and perseverance, with the head alone out of water, that they frequently overtake fishes in fair pursuit. They live in the sea, and have been met with a thousand miles from the nearest known land. The larger birds of this kind sometimes weigh as much as eighty pounds, and in their stomachs have been found ten pounds' weight of pebbles and large stones, swallowed, no doubt, to assist the gizzard to pound up the food submitted to its action.

The frigate-bird, the petrel, and the albatross, seem to range through the air over the whole extent of ocean, from coast to coast, of the Atlantic and Pacific. The pelican, also, and the cormorant, are far more nearly dependent on water than land. They are all birds of powerful and rapid flight, feeding on fishes, and rarely seen far inland, though often stretching to great distances across wide expanses of sea.

Thanks to them, we have those accumulated masses of guano which help to fertilise our lands. Some idea of the extent of these masses may be obtained when it is stated that, on the island of Iquique alone, upwards of six millions of cubic feet of guano have been removed within the last thirty years, while in the year 1854, not less than half a million of tons were exported from the Chincha Islands.

Although there is no reliable evidence of the existence in the ocean of a gigantic reptile resembling a serpent, there are undeniable sea-snakes, poisonous, but of no large dimensions. Lizards also, three or four feet long, and inoffensive, are met with in the Pacific, and turtles of large size are common throughout the warmer seas, being occasionally drifted into cool latitudes. Green turtles from the West Indies, nearly half a ton in weight, have even been taken on our own shores. These animals live entirely at sea, only visiting warm shoals for the purpose of laying their eggs, which are hatched in the sun. Turtles of enormous size have also been found in the warm seas of northern Australia.

We are apt to look upon fishes as the only fit tenants of the water, and doubtless they are in some respects the most characteristic of all, the strangest in form, and the most distinctly adapted to such a medium. And although we find in water quadrupeds, birds, and reptiles, they all exhibit exceptional modifications of the structure of animals which breathe air, and are usually organised to move on land or through the atmosphere. On the other hand, it is a rare exception to find fishes capable of existing for more than a short time out of water. This is well known to be the case, although we certainly have the flying fish, that leaps through the air, the perch that climbs trees, the frog-fish that can crawl about a room, the hassar that travels a whole night from one pool to another, and the goby that burrows deeply into clay.

Fishes breathe by means of the air contained in water, and are suffocated if their gills or breathing apparatus become dry. They move not only by fins and tail-contrivances of the nature of flexible oars, well adapted to beat the water, but also by means of the wonderful flexibility of their bodies, which glide and slip through the water with perfect ease. Living in a medium of nearly the same specific gravity as themselves, they have scarcely any weight to support, and float at any depth without effort. Some, indeed, are usually limited to certain depths, but this seems rather for the sake of food than for any other reason.

Fishes move with a rapidity impossible to other animals whose density being much greater than the medium they move through, the animal needs constant muscular effort to advance at all. Thus, we find that when a ship is sailing or steaming at its swiftest speed, fishes will quietly, and without apparent effort, swim round and round the ship as if she were at rest, and continue to accompany her from day to day for hundreds of miles. No words can do justice to the bright colours, the quaint and droll or ugly forms, or the singular appendages of fishes.

The Ray of warm seas, with its broad, flat, angular body, twelve or fifteen feet wide, terminated by a tail five feet long, armed with a sharp arrow point, conveying poison to the wound it makes, is as unsightly and disagreeable an animal as can well be imagined, while the little sea-horse of the Mediterranean is in the highest degree picturesque, resembling the mediæval figures of a flying dragon. The globe-fish and porcupine-fish are bladders stuck all over with spines; the sun-fish resembles the head and shoulders of a larger animal cut off shortly and abruptly by some accident; the sea-wolf attains a length of six or eight feet, and has a formidable apparatus of teeth, compared with which even the alligator or the shark seems powerless; the sword-fish and saw-fish are provided with weapons capable of piercing and being completely buried in the keel of a ship; and a curious fish called the angler, or sea-devil, catches its food by means of a natural line, consisting of two slender appendages to the head, slightly flattened and broadened at the extremity, which, by their colour, attract the unwary prey while the owner is buried in mud or sand.

The sea is highly important as a never-failing source of food to the human race; but the prejudice that exists with regard to particular kinds of fish is often so strong, that no motive or hard necessity is sufficient to induce a hungry population to try the experiment of converting them into food.

There are, however, some kinds of which the consumption is almost inconceivably large. In shoals, miles in length, and so thickly congregated that there is no room for a boat, the common herring rushes annually to the north-western coast of Europe, filling all the lochs, fiords, and inlets from Norway to Normandy. More than half a million fish have been taken in one night by a single boat. Upwards of 200 millions of fish have been exported in one year from one port in Sweden, and about four hundred sloops are employed in the herring trade at Yarmouth, three of which alone, belonging to the same proprietor, landed, in the year 1857, nearly four millions of fishes. Nor is the herring the only animal thus abundantly supplied; instances are on record of 25 millions of pilchards having been taken on shore in one port in a single day. Even of cod, a much larger fish, the quantity taken each season cannot average less than 250 millions; and other fish, as the mackerel, the salmon, and the tunny, rank among the principal food at certain seasons of the year, of large populations of several European countries.

Nature has amply provided for this vast consumption and destruction of full-grown fishes. The cod annually produces more than nine millions of eggs, and the sturgeon more than seven millions: while flat-fish, mackerel, and herrings, all multiply by millions to maintain their kinds against their numerous enemies. There is no fear of the supply of fish failing out of the ocean, but almost all kinds, especially those which come in large multitudes at fixed seasons, are subject to occasional and apparently capricious wanderings. The varieties of temperature during different seasons, may in some measure account for this, but not entirely; and the open water habits of the animals require more study than has hitherto been devoted to them to enable us to determine many points in their natural history.

Fishes are chiefly obtained from near shore or in shallow water, but there is no reason to doubt that they occasionally occupy considerable depths. The crustaceans, also—the crabs and lobsters, the shrimps and prawns and cray-fish—are met with exclusively in the neighbourhood of land or in some of those great masses of seaweed that float in open water in the mid-Atlantic. Crustaceans are very curious animals. Commencing life with a head preposterously large in proportion to its size, the young crab emerges from the egg with a long forked tail, but no body, and occupies its time in turning head over heels till it casts its first covering and alters its proportions. The true and recognisable crab does not, however, even then appear: this singular form being at last elaborated after a series of changes and transformations which can only be likened to those of a pantomime. Of the crabs, some occupy their own mansions, which they leave periodically as their substance increases and requires larger accommodation: while others, not constructing houses for themselves, occupy shells which they seize for the occasion, and which would seem suitable enough, if one may judge from the tenacity with which the tenant retains possession.

The lobster, the prawn, and the shrimp, are less varied in their habits. They all change their shells from time to time as they grow too large for them, and, during the period of change, conceal themselves in holes and mud.

The little complicated shells which, under the name of barnacles, adhere to ships' bottoms, or which, under the title of balanus, are found on every rock, and on many shells by the sea side, are also crustaceans. Many others exist, adding to the list of marine animals, and each is important in its own sphere.

Of annelids or worms, a few are strictly marine, and among these are some that are the most curious and most highly-coloured, as well as the most puzzling, of the creatures inhabiting salt water. The sea-mouse is one of them; the serpula, its tufted head projecting from a stony tube, is another; some, again, assume for defence particles of sand, shell, or stone: while others are able to pierce stone, and eat into almost any substance they come in contact with.

Of all annelids, few are more interesting than the unknown inhabitant of a little tube brought up from the sea bottom, beneath some miles of water. At this vast depth living animals are to be found, and among them are representatives of those who penetrate all organic substances in search of food. Let our telegraph companies tremble, and endeavour to take precautions in time: for their wires, buried at the bottom of the sea, are pursued in mid-ocean by relentless foes bent on destruction.

Soft animals, often defended by shells, abound in the ocean, and form an important class of its inhabitants. The cuttle-fish is the emperor of such molluscs, and is represented in all seas by some worthy cousin. The cuttle-fish, or squid, of our own shores, ranges under various representative forms, both in the Atlantic and Pacific; but there is one variety covered and protected by a chambered shell, the nautilus, which is confined to the southern seas. Few animals inhabiting the ocean are better adapted for attack or defence than these. They are often of large size; they have powerful jaws and beaks; very long arms, on which are suckers of a peculiar kind, holding fast to any object they touch; and many of them have a provision of dark fluid, which they eject into the water when they desire to obscure it, either to escape from enemies, or conceal themselves from their prey. Amongst the most unsightly, these animals are also the most highly organised and the most powerful of their class, and though only used locally, they are well adapted for human food. They are the last representatives of a group formerly much more important in the seas than they now are.

Innumerable multitudes of animals, extremely varied in size and shape, brilliant in colour, and of very peculiar habits, all belonging to the class mollusca, inhabit the ocean at various depths, and form a large part of the food of many important tribes of fishes. Nothing can be conceived more delicate and beautiful than some of them, no limit can be expressed in figures to their numbers, and they show a series of transitions from animals totally undefended, to others, such as the oyster, closely protected in a solid stone construction. The shells with which these creatures are fortified are again as strangely varied and as singular as any productions of nature. We may mention as examples the spider-shell, the cone, the cowry, the wentle-trap, the top-shell, the harp-shell, the Venus-shell, and the clam. Few things are more interesting than to watch them as the animal comes out from its coat of mail or puts forth its feelers in search of news and food. In the same way we may examine the oyster, follow the indication of the ship-worm or stone-piercer from the bored surface of wood or stone, dredge for the shell containing the imperial purple dye, and endeavour to learn something of the rich treasures of the sea in this wonderful department. The treasury is not easily exhausted. It will yield abundance of useful and valuable information to any one who will patiently examine its stores.

There are very curious shells found in almost all seas, some of which are distinguished from ordinary kinds, as much by a peculiar texture of the shell itself as by an arrangement of the gills in the animal. The *Terebratula* is one of them, and, like the cuttle-fish, it is as interesting in reference to former time as to present existences. Terebratuliform shells and nautilus-like shells, in fact, are among the earliest records of creation in the various rocks containing fossils, and their remains are especially abundant in the oldest rocks. Modern species are found in our own seas generally at some depth.

Very minute compound animals, at one time regarded as polyps, but now referred to mollusca, are sufficiently common among the sea-weeds on all shores, and float in open water, being not unfrequently phosphorescent. They glide sometimes through the sea in long chains of united animals, and they are exceedingly remarkable as illustrations of a method of succession not otherwise observable. A Salpa, as one of them is called, bears a marked resemblance to its parent or offspring two generations off, but never bears any resemblance to its own immediate parent or young. This singular and puzzling, but well ascertained condition, extends to many animals, chiefly of low organisation.

Star-fishes, sea-urchins, and such-like creatures, are essentially marine. They owe their name to their divergent rays, covered often with spines and suckers, and they are exceedingly remarkable for their habits as well as their form. Such animals present many curious varieties of structure. Some are provided with stony plates fitting together and forming a defence; in ancient times these stony creatures were wonderfully varied and very common. The lily-stars, as some of them are called, are now nearly extinct.

There is a kind of snake-like star-fish very widely extended, and not very uncommon in our own seas, in which the long rays diverge from a compact centre, and twine themselves round any object with which they come in contact. It is not easy to imagine the astonishment and delight of Dr. Wallich, the naturalist on board H.M.S. *Bulldog*, employed in sounding the ocean from Greenland to Labrador, when he saw clinging on "like grim death" to the lower extremity of a line that was being drawn up from an Atlantic depth of some fifteen hundred fathoms, an *Ophiocoma*, or "brittle-star" of this kind, living still after the removal of the enormous pressure of water under which it had hitherto existed, and retaining the arms which, in ordinary cases, it throws off with singular facility when alarmed!

This, and a number of companion specimens, brought up at the same time with the mud from the bottom, were by no means of microscopic size, each of the arms of the star-fish being between two and three inches long.

Thus, it is certain that these vast depths are not untenanted, and that the presumed impossibility of animals living with very little light and air at depths so enormous that the mere pressure of the water is equivalent to upwards of two tons on every square inch of surface, is an unnecessary assumption, and another proof that what is quite contrary to our experience and utterly opposed to any analogies we can draw, may still exist and belong to the usual order of nature. Many of these star-fishes having been brought home, they remain to be their own witnesses, and they differ so little in appearance from some common kinds, that an ordinary observer would pass them by, little aware of the fact of their having lived under circumstances so utterly inconceivable.

A singular class of marine animals have recently attracted much attention, and are now to be met with in many drawing-rooms. Some of these, indeed (the *Acalephæ*, or sea-nettles), inhabit the open ocean, and, being of large size, are not imprisoned in our marine vivaria; but others (true polyps) are among the chief ornaments of those interesting menageries. The Medusæ, or jelly-fish, are sometimes two or three feet across, or even more, and when removed from the water, look like huge masses of nearly transparent mucus, which, if left alone, soon evaporates, hardly leaving behind a few grains of solid matter. Others are far smaller, and exquisitely beautiful; others again sting like nettles, and many of them are concerned in producing that marvellously beautiful phosphorescence of the sea, which occasionally ranges for vast distances. These animals serve to feed the whales as well as to light up the ocean, and in their young state they form exquisite little groups of individuals of the most fantastic shapes, formerly supposed to be polyps.

The sea anemones and polyps generally consist of a cylindrical cavity opening above in a wide mouth, round which are arranged numerous feelers, which the animal extends in search of food. Some of them secrete no hard stony matter, but others form those constructions known in all seas to a greater or less extent, and recognised as corals. Their variety is endless, and the mass of solid matter thus accumulated almost beyond belief. Separated incessantly from sea-water, which re-absorbs it again as readily from every limestone rock with which it comes in contact, the mass of calcareous matter enclosed by these singular animals is constantly receiving additions, and, being little subject to change, remains from one generation to another, accumulating into masses which form a sensible proportion of the earth's superficial crust. Since, however, the animals constructing the large masses of coral which form islands in the Pacific Ocean, can only continue their labours within moderate limits of depth, it would follow that the mass of limestone is only a superficial plate, were it not that in many cases the districts thus built upon are, for some reason, constantly descending below the level of the sea, while some other tracts of land and sea-bottom are known to rise and swell slowly upwards. The descending land, when occupied by the coral animal, is constantly supplied with additions reaching the surface, and thus sometimes forms a perpendicular wall to the depth of hundreds of fathoms.

The beautiful red coral of the Mediterranean, fished up from moderate depths every year, is not of this kind. Like the other branching varieties, it does not form compact masses.

There yet remains one, and that not an unimportant group of animals, that may fitly take rank as contributing to the wonders of the sea—the constructors of minute, many-chambered shells. Such animals are mere lumps of jelly, capable of extending themselves in all directions, and capable also of forming shelly coverings singularly elegant and complicated, but so small that their shape can only be recognised under a powerful microscope. Multitudes of individuals, however, combine to produce even a single shell, and thus the individual animals are almost infinitesimal. Will it be believed that such animals are spread over thousands of square miles of ocean, that they occur both at the surface and at depths the most considerable that have yet been reached, and that their remains compose 90 per cent. of the mud that forms the sea-bottom at those depths? The stomachs of the brittle-stars, brought up in mid-Atlantic in a living state through nearly two miles of water, were found to contain half digested food of this kind; and although it may never be possible to obtain the creatures themselves alive from such depths, the fact of their living there is now clearly proved. That they have long inhabited those cold, silent recesses is also evident, since the whole bottom of the Atlantic seems strewed thickly with a fine mud entirely made up of their remains, associated only with a few transported stones, and a rare sprinkling of sponge spicules and flinty cases of the simplest vegetable cells.

It remains only to treat of these sponges, the last of the animals belonging to the sea. The sponges are very widely spread, and each consists of a curious network clothed with soft gelatinous matter. At frequent intervals are open spaces through which water is made to pass, and in this way food is brought. It is not a little curious to watch these lowest forms of life in the water, where their brilliant colours are as remarkable as the shaplessness of the masses they present. Such opportunities are now not rare, as the animals can be kept in vivaria prepared for the drawing-room.

In thus describing in a very general way some of the principal tenants of the sea, we have indicated the wide range of many of these animals, and the facility with which they move across tracts of ocean of very different temperature. In this respect there would seem nothing to confine the more active of the marine animals to definite positions. But they also are grouped, and there are characteristic and representative species. It is, perhaps, even more striking in these cases than where the powers of locomotion are more limited, to see the reality of the groups and trace their proper homes.

The inhabitants of fresh water, though to some extent different from those of the sea, have many points of close resemblance, and need not detain us long. Not a few living usually in the sea breed in rivers, and others dwelling in estuaries or tidal rivers adapt themselves to each variety. There are besides these many species of fishes altogether confined to rivers and lakes, but they do not affect the general argument.

Of land animals, the lower forms of life are less remarkable, and less fitted for general illustration, than is the case with the inhabitants of the water. No doubt they abound, but they are not prominent. Crustaceans are chiefly aquatic. Molluscs, also, to a large extent require the water. The exceptions are sometimes striking, as in the cases of the snails, some of which, living in America, are of extraordinary size and beauty; but they are few. Annelids or worms are numerous, but less varied in form and colour than those frequenting the other element.

Of all land animals insects are the most interesting, partly from the variety of specific forms they assume, partly from the changes they undergo. They probably perform a very important part in the general economy of nature, taking up decaying animal and vegetable matter, and assimilating it with extraordinary rapidity, so that the ill effects of an excess of putrescent particles in the air is brought within moderate limits. Besides the insects are the spiders, helping to keep a balance of life. Insects pass through very curious changes in different stages of their existence, being aquatic in one and terrestrial in another, feeding at one time exclusively on flesh, and at another time on the juices of flowers, varying so much in size and appearance that no identification would be possible, did we not actually trace the change in the same individual. It must be evident that no one could guess the identity of the grub and maggot with the beetle, or of the caterpillar with the butterfly. Being familiar with them we pass by these marvellous transmutations without notice, but the wildest dream could hardly suggest anything more extraordinary, or more unlikely to happen, than many of those changes that pass under our eyes in each successive season.

As a general rule insects increase in abundance and variety from the poles towards the equator in horizontal space, and vertically they increase from the unpeopled heights in the atmosphere to the common surface of contact between land and water. But the increase is not regular. Many parts of the southern hemisphere are poor in species, especially Australia. North America is less rich than Europe in the same latitude. Asia is also poor. North Africa, the Brazils, and the west coast of South America, and Mexico, are more rich, but not very remarkable. Central and tropical America, and some parts of tropical Asia, are the richest of all.

So, again, there are many well marked regions. Eastern Asia and China are very different from Europe and Africa. In South America, Guiana is quite unlike the equinoctial districts of New Granada and Peru.

It is interesting to observe the nature and efficacy of certain natural barriers against the spread of various species of insects.

Mountain chains are the most effectual, even when there are passes of only moderate altitude. Rivers are very partially available for this purpose. Oceans, even, are not always sufficient. There are some butterflies spread over the whole world; others confined to very small districts. Certain stagnant pools appear to have a creation of their own, while the winds carry the insects or the eggs of some species for thousands of miles. Some insects, as the mosquito, are equally troublesome at the poles and under the burning sun of the equator, but they long remain undeveloped in uncongenial climates, appearing only when, owing to some cause, the conditions are for the time favourable for their existence.

Wood, conveyed naturally or accidentally from one country to another, has often carried with it the insects that attack it at home. It has happened that when these insects are once introduced, they will feed on the trees indigenous to the new habitat.

The abundance of insects in favourable localities is inconceivable to those who have not had personal experience of the fact. The great rivers of tropical America are perhaps more troubled in this respect than other localities, and in some places, other animals, including man, have been driven away by their enormous accumulation. Even in the plains of Wallachia and Hungary, and in Lapland, they crowd the air to such an extent that it is difficult to breathe without swallowing some of them. Humboldt has said that, on the Upper Orinoco, they succeed each other with such regularity that the hour of the day may be guessed pretty accurately from them. On the other hand, it is said that our common house fly was first conveyed to the South Sea Islands by the English; while the honey bee, now exceedingly common throughout North America, Australia and New Zealand, was introduced into these countries by the English. The native bees in these countries are without stings. The *tset-zse* fly of South Africa is almost equivalent to a cattle-pest, but it is strangely limited in its range.

Notwithstanding the remarkably definite grouping of insects generally, there are many that migrate to a great distance, taking long flights, and even changing their route from time to time. Thus, locusts are the natural inhabitants of sandy deserts, where their eggs are hatched; but they occasionally fly in vast masses, sometimes crossing more than a hundred miles of sea, and reaching nearly two thousand miles from their place of starting. Locusts, however, are essentially migratory, but there are other insects that occasionally take wing, although it is not their usual habit to travel in company. Lady-birds are examples, and both they and butterflies are sometimes driven, apparently by stress of circumstances, to advance in dense masses. Dragon flies also have been noticed to do so.

There seems no reason for these curious peculiarities. Certain kinds of ants are capable of moving in a body for considerable distances, and, in this case, nothing will stop them.

Whatever may be the nature of the instinct of migration, it is, at any rate, so powerful as to over-ride every other, and thus there seems to be a means provided by nature to push certain forms of animal life into such conditions as may be favourable, in order to conquer from time to time the tendency to centralisation, which is otherwise a law of nature. There is in this, as in so many cases, a perpetual contest, resulting in the mixed arrangements we find everywhere, and it is important to recognise the fact that this also is a law of nature. When, therefore, we see that, in most countries, there is a peculiar and distinctive fauna, as well as a characteristic flora, and that animals, like plants, have a metropolis,—or central point, whence they seem to diverge in every direction,—it is evident that the study even of a local fauna, may lead to a knowledge of some of the great laws of nature.

Passing to the consideration of the land animals of higher organisation, we find the distribution of reptiles both peculiar and interesting. These animals are for the most part limited in their power of locomotion, and not endowed with much energy. They flourish chiefly where man is absent or sparingly distributed, or at least where civilisation has not introduced modifications. A few of them migrate, but they do not travel very far. Of the marine species we have already said something.

There are four divisions of reptiles now living which may be illustrated respectively by the frogs, the serpents, the lizards and the tortoises. The frogs are the most widely spread, reaching nearly from the Arctic circle to a latitude of about 50° S. They are all chiefly abundant in warm, damp countries, and increase in number and variety as we approach the equator; the number of species in the torrid zone being fully double that found in temperate latitudes. Of all places in the old world, Java and the adjacent islands seem to be the best fitted for these animals. America possesses half the known species.

All, without exception, of the known species of reptiles of America are distinct from those of the old world. The Australian species are all unlike those of Asia. The Asiatic species are much sub-divided, and few of them are identical with those of Europe or Africa. Some of the frogs and serpents are limited to exceedingly small districts, and few of them range widely. Most of the European species of frogs, it is true, extend into Asia and North Africa, but the characteristic species are generally limited to a very small space. The toad of Surinam, the largest and ugliest of existing species, is found only in that island. A Brazilian toad ten or twelve inches long, and another gigantic species from Carolina do not leave their own neighbourhoods.

Although there are serpents in the colder parts of Europe, the number of species is small, the size of the individuals insignificant, and their venom, except in one case, is not dangerous to man. Of the three great families of venomous serpents, only that containing the viper is met with in cool northern latitudes in the Old World. In other countries the case is very different. Thus, in North America, the rattle-snake abounds. In Australia, also, in the temperate zone, more than half the serpents are dangerous. In Africa, it is also said that half, or a third of all the snakes seen are distinctly poisonous. In India, there are also several. The hooded snakes (cobra) of India, the Egyptian asp, the whip snakes, and all the sea snakes are the most venomous and ferocious, but they are all confined to very narrow limits. The common viper is that which ranges most widely, reaching from England to central Asia, and from the Alps to the Arctic circle.

Tropical Africa and tropical South America are the countries where are the most gigantic and powerful of these singular animals. The boa is chiefly American; the largest species being found in the tropical forests of South America, where it hangs from the trees, watching its prey. Some species are twenty feet long, and they are partly aquatic. The Pythons are the corresponding African species, and they spread through Africa and Asia as far as Java and China. Other, but quite different species, belong to Malacca, and others, again, inhabit New Guinea and Australia.

Of crocodiles, there are many species, most of which are strictly limited in range, and quite characteristic. Of these large reptiles we may name the caiman, or alligator of America, the gavial of the Ganges and India, two African species, (one on the Nile and one on the west coast) two Madagascar species, and one Australian.

In America, there are two species of crocodiles and five alligators. Some few of the species range to a height of three or four thousand feet above the sea, but they do so only by following towards their sources the great rivers. They live chiefly in mud, hybernating occasionally during long continued drought. Crocodiles do not extend into Europe at present, not perhaps so much on account of climate as for want of other favourable conditions. Lizards, however, represent the same natural family. Of these, there are nearly twenty species in Italy, and they reach up to almost 5,000 feet on the Alps. They extend also, though more sparingly, through northern Europe.

Asia is very rich in lizards; one of them (the *draco volans*, or dragon) having a membrane like that of the bat, enabling it to take long leaps in its pursuit after insects. The gecko of the Mediterranean coasts, and the chameleons chiefly inhabit northern Africa, but reach Spain and Asia. These are the most characteristic forms. The skink—a burrowing lizard —is represented in Africa and Arabia and also, but by different species, in Australia and the Indian Archipelago. A very curious marine lizard, feeding on sea weed, exists in the Galapagos Archipelago, and represents species now extinct.

Of tortoises and turtles,—the former inhabiting the land and fresh water, and the latter the sea,—there are species very widely distributed. In the East Indies, there are some land tortoises of large dimensions and very beautiful; others are peculiar to Brazil; others are found only in Demerara. There is a species found in the Galapagos islands which weighs more than a quarter of a ton, when full grown. The European species are small; the largest of them inhabits the shores of the Mediterranean. Fresh water tortoises are also widely distributed, but the largest number of species are American. There are fresh water turtles, different from the emys or fresh water tortoise. They are large and voracious. They are found in the Nile, the Ganges, and the Euphrates. One is met with in the rivers of Java only; another is common to Java, Borneo and Sumatra. The sea turtles, of which the green turtle and the hawk's bill turtle are the most familiar,— the former as food, the latter for its shell—browse on sea weed in tropical waters, and grow to enormous size. The former belongs to the West Indies. The most valuable species of the latter is obtained from the Molucca Islands and the coast of New Guinea, but there are species in the Gulf of Mexico, and even in the Mediterranean.

It is interesting to notice that certain large districts of the earth are now almost without reptiles. Thus, the islands of the Pacific, Tierra del Fuego, the Falkland Islands, may be named, as being altogether free from frogs, toads, and snakes of all kinds. In Ireland, reptiles are almost unknown.

Birds, unlike reptiles, are provided with great power of locomotion, and they often migrate to great distances. By means of their wings, they are capable of overcoming impediments which prevent the advance of all other animals, and in all respects they seem to be enabled to distribute themselves over the earth at will. But they are not, for that reason, free from the great laws governing and limiting the distribution of animals generally. There are for them, as for reptiles, certain central points, whence typical forms diverge, and which may be claimed as their birth-place.

There are six natural groups of birds. Birds of prey, climbing birds, (parrots and wood-peckers, &c.) warblers, gallinaceous birds, (domestic poultry and food birds) waders, and swimmers. Of all countries, tropical America is the richest country in birds, and contains some of the most curious varieties of form, colour and proportions. Europe, however, comes next in order, and is even much richer than America in songsters, or birds, whose warbling notes make the woods resound with melody. Many birds are found to range through the whole of the Old World, extending even to America, and identical in species from pole to pole. The birds of prey, waders and sea fowl are among the most remarkable of these. The common house sparrow accompanies man wherever he goes, and seems as much at home in Bengal as it is in Britain. The peregrine falcon extends over Europe, America, and Australia. The common heron seems indigenous, both in the Old and New World. Owing to the habits and powers of birds, they naturally range widely in vertical space, and are met with at all elevations, on the loftiest mountains of the earth.

But although birds migrate systematically and travel accidentally to great distances, their breeding places are in general greatly limited. Thus, of upwards of five hundred species of European birds, there are certainly four hundred that do not habitually leave that continent and the adjacent islands. Of the Brazilian birds, whole tribes of parrots and humming birds never quit the forests where they were bred. Each country, in fact, is characterised by some typical group.

The thick-billed birds, living on seeds, and including the nightingale, redbreast and wren, the finches and linnets, the sparrow, and many others very familiar, are the characteristic birds of Europe. Many of them are peculiar to our continent, though others, as the nightingale, come to us from northern Africa, where they may be heard singing in the woods from morning to night, late in autumn. The same is the case in Asia Minor, and especially in Armenia. There, however, we find already the brilliant plumage and more developed forms of the tropics; and there, also, is the home of many useful birds, now domesticated and apparently almost indigenous. The gallinaceous birds, especially the pheasant and the peafowl, are as characteristic of Asia as the singing birds are of Europe. There, also, these birds are mixed with very striking and beautiful specimens of climbing birds, especially parrots, which range in one form or other, though always with distinct species, throughout tropical Asia, reaching Australia and reappearing in South America. It is impossible here to do more than allude to the marvellous brilliancy and beauty of the plumage of the large tropical birds of western Asia, although they are fully rivalled by their competitors on a smaller scale in the Brazilian forests.

In the Indian Archipelago we have other examples of the most singular beauty of form and brilliancy of colour in the plumage of the characteristic birds. The bird of paradise, the orioles, the hornbills, the pigeons, and the Argus pheasant, are examples worthy of special mention. In speaking of the peculiar birds we must not omit the cassowary, whose powers of locomotion are limited, but which yet has a very wide range in the south-eastern islands of Asia.

Africa is also rich in birds, many of which may compare with those of South America, although there are very few identical species. Besides a number of birds of very beautiful plumage and very peculiar habits, Africa possesses the ostrich, which ranges through a vast extent of country, and represents other birds of somewhat similar structure in America and Australia. The ostrich extends into Arabia, but its home and metropolis is on the sands of Africa. Many of the birds of the south are different from those of the north. Among those common to the whole country is a remarkable serpent-eater (the secretary bird), the honey birds, representing the humming birds of America, and the parrots, also representative, and very abundant. There are also many singing birds, but these are chiefly northern.

South America is marvellously rich in birds. The condor of the Andes builds its nest 15,000 feet above the sea, and is seen wheeling in circles above the mountain summits at the height of much more than 20,000 feet. It extends to the Straits of Magellan, but has not been seen on the northern side of the Isthmus of Panama. Besides the condor, there are vultures of various kinds, and of magnificent proportions, one of them living on vegetable food. Parrots range throughout, and there are gallinaceous birds, but all totally different from those of the Old World. There are also peculiar species of the ostrich.

But it is chiefly the humming birds that characterise this singular district. There are more than one hundred and fifty species, varying in size from that of a bumble-bee to that of a wren. They reach down to nearly 40° S. latitude; but very few species are met with in Central or North Amercia, and not many in the West Indian islands. They are found up to an elevation of 12,000 feet in the Andes of Bolivia and New Granada. They are accompanied in the Brazilian forests by numerous climbing birds and many richly-decorated parrots.

Australia and the adjacent islands, including New Zealand, are very remarkable for their birds, all of which are either representative species or altogether *sui generis*. There are no true gallinaceous birds, but the lyre-bird represents the Argus pheasant. The parrots and the pigeons, the cereopsis goose, the emu, and above all the apteryx, are all so peculiar that they hardly admit of comparison with familiar birds in other countries. The modern *apteryx* represents another and much larger bird, of similar habits, that has only recently become extinct, but that is only known by the bones of its skeleton and the fragments of the egg shell. Some of these extinct birds must have attained at least double the bulk of the largest ostriches.

Thus it is clear that in the case of birds, as of reptiles and fishes and the invertebrata, there are certain groups distributed in certain parts of the earth, all more or less characteristic, and all, though adapted to existing conditions, appearing to connect these with some former and different conditions, when the races now less important were the prevailing types of their class.

This conclusion will be confirmed when we consider the case of the other inhabitants of the land. These include the most important of all species, for they are all animals provided with high and complex nervous organisation. For the most part they possess intelligence; and the females of all the varied species bring forth their young alive, being provided with milk, a peculiar and convenient food, supplied to the young animals during the interval that elapses between birth and the time when they have sufficient strength to provide for themselves. These animals are technically called *mammals.*

Mammals are very widely distributed over the earth. Some are confined to the surface, some burrow under the surface; many, as we have already seen in speaking of marine animals, permanently inhabit the sea. A few may be said to inhabit the air. They have great powers of locomotion, though these are in no case so efficacious as the wings of the bird, and do not allow of either the same kind or amount of migration.

There are several distinct natural groups of mammals, which are distributed in a very different manner on the earth. Of all these, man is at the head. Next in order are the four-handed mammals, such as monkeys. The gorilla and chimpanzee are the most striking examples, and in some respects approach most nearly to man; but while man in some one or other of the principal sub-divisions of his race is enabled to inhabit all parts of the world, from the poles to the equator, these monkeys are very strictly limited to small tracts of country, and can hardly be removed from their own soil and climate without death resulting. It is well known that western tropical Africa and tropical Asia are the habitats of these singular animals. Others, but very different species, range through Asia to the islands of the Indian Archipelago. Others, still very different in structure and habits, are found in South America. There are few things more remarkable than the wide distribution of the human race and its wonderful adaptability to change, as contrasted with the strict limitation of all the most characteristic quadrumanes. It may be said, in a general way, that the tropical forests are the chief abode of the monkey tribe; and that while Asia is the especial home of the ape, Africa exhibits the best types of the baboon. All the monkeys of America have prehensile tails.

A large and important group of flesh-feeding quadrupeds is the carnivora—these are chiefly abundant, and on a large scale, in the tropics. The gnawing animals or rodents, and the ruminating animals, are more characteristic of temperate climates. The pachydermata abound in certain localities, both in the tropics and in sub-tropical and temperate plains. The edentates and marsupials are singularly local; the winged quadrupeds or bats are tropical for the most part, but range widely; and the cetaceans are aquatic. Some quadrupeds are capable of migrating, but for the most part they retain their natural habitats, except when transported by the agency of man.

Asia is the metropolis of a large number of important groups of quadrupeds that have in the course of time spread over most parts of the great continent, and that have even been transported to America to the destruction of native tribes. The great mountain chain of the Himalayans and its offsets divides Asia into two distinct provinces. Western Asia is also very distinct from the eastern part of the country, and the table lands of the north and south exist under totally different conditions. Thus, while in the northern plains we have the rein-deer and the elk, the wolf, the white and other bears, the lynx and the flying squirrel, meeting the Bengal tiger and the panther among the snows of the mountains and on the banks of the Obi,—these are mixed towards the west with several species of horse and antelope, various goats and sheep, the camel, and a number of ruminating animals that approach European forms. The true horse and the ass, indigenous, perhaps, in Central Asia, make their appearance in the lower plains and steppes, and there meet the familiar quadrupeds of northern and southern Europe.

South of the mountain chain is one of the chief habitats of the carnivora, where are species referred to upwards of sixty genera, and where also there are many bears, hyænas, and jackals, with the larger pachyderms, including the elephant, the rhinoceros, and the tapir, and two representatives of the edentates, whose home and metropolis is on the other side of the great ocean. These two species are scaly ant-eaters. They range through India to China, and extend into Formosa. The Indian Archipelago contains two zoological provinces. One of them is that of southern Asia, including the flying lemurs, vampire bats, civets, ichneumons, polecats, and others; tigers, porcupines, elephant, tapir, the babiroussa, two species of rhinoceros, and large deer. On the other side of a narrow, but deep channel, we find a totally different group connecting with the Australian fauna, which is altogether distinct from that of Asia.

Tho Australian, or Austro-Malayan region, comprises all the islands lying west of a narrow channel. They include as their easternmost limit the large islands of Java, Borneo, and the Philippines. The Celebes, the Molucca group, and New Guinea, are islands that must be added to Australia. In Celebes and the Molucca are one species of ape, one civet, one deer, and one of the bovidæ, mingled with numerous marsupial flying squirrels, eastern opossums, and kangaroos. In Australia almost all the species are marsupial, by which is meant that the female is provided with a kind of bag or pouch (*marsupium* a pouch), in which the young, who are brought forth at a very early period, are conveniently carried by the mother till they are able to shift for themselves. This remarkable contrivance seems well adapted to a country where there are wide tracts without water during a large part of the year. All the principal animals of other countries are represented in Australia by species having this peculiarity, but the habits and form of many of them are exceedingly anomalous. Thus the kangaroo, one of the most familiar, rests on its hind legs and tail, its fore legs being extremely short. It moves by bounds, aided by the tail. Besides important groups of marsupials there are also two aquatic edentates, one a mole, with a mouth and bill resembling a duck, the other a hedgehog covered with quills. Australia is thus an absolutely perfect zoological province, so far as mammals are concerned; but the associated islands to the north have received additions from the adjacent land. Since its human occupation Australia has also received numerous fresh quadrupeds, some of which multiply very rapidly.

Africa is the zoological province of great interest. It contains a peculiar elephant, a rhinoceros, and hippopotamus, peculiar species of horse, a vast variety of antelopes, and a great variety of feline animals. Of three hundred and fifty species of quadrupeds two hundred and fifty are either peculiar to the continent or have had there their origin.

South America may almost be compared with Australia as a great zoological province. Most of its quadrupeds are, however, moderate in size, not remarkable for strength, and inferior to the representative species in the old world. Thus the llama and alpaca represent the camel; the little myopotamus (a river mouse) the hippopotamus; the puma and jaguar the great carnivora of Bengal; and the tapir the elephant. In addition to these are the sloth tribe, the ant-eaters, the small but curious sapajous and spider-monkeys, the chinchilla, and a few others of less importance. North America, with few of these, contains a remarkable group of large ruminants, including the bison and the musk ox. It also has the grizzly bear, the racoon, several opossums, and several carnivora and rodents. Some of these seem to have been introduced from the Old World.

Such, expressed very briefly, is the distribution of quadrupeds in the world. It agrees in a general way with that of other tribes and classes of animals, and with that of plants. To account for it we may no doubt assume that each district was at some distant period a detached land, for which was created a special flora and fauna, and that by degrees these detached lands have come into contact at various points. We must in that case admit that the lands have been constantly altering in climate and position; constantly becoming less fitted for the tribes once adapted to them, so that the original species have dwindled and become exhausted, or have been partly replaced by new creations, or by emigration. If this be so, the system of nature would seem to be imperfect, and always getting out of order,—a conclusion neither reasonable nor desirable.

There is, however, another alternative. It may be that, according to the original constitution of the universe, all these changes of circumstances were foreseen and provided for; that each alteration of climate as it occurred was met by a modification of form; that where a new species was needed, there a new species grew, out of some one that had performed its task; and that, apparently by a system of development and the force of circumstances, but really by the operation of that same series of laws that keeps the earth and the sun in their places in the universe, all the required changes were wrought out. The reader may elect which of these two hypotheses is that most worthy of an Almighty Power.

CHAPTER XX.

DISTRIBUTION OF PLANTS AND ANIMALS IN TIME.

About two centuries ago a great controversy raged in Italy as to whether certain stones imitative of organic shapes were produced by a peculiar fatty matter, *materia pinguis*, set into fermentation by heat, or were porous bodies (originally real bones and shells), converted into stone by the action of a "lapidifying juice;" or whether possibly they may not have been mere stones and earthy concretions—*lusi naturæ*—sports of nature, thrown off in moments of leisure as a relaxation from the heavy labour of carrying on the every-day affairs of life.

The stony representatives of animals and plants thus existing beneath the soil, in sand, gravel, limestone, and other substances, were, at the time alluded to, described in general language, with all other mineral substances, as *fossils*, or things dug up.

By degrees these imitative organic shapes were found in so many places, and in such great abundance—they simulated so exactly the remains of animals and vegetables—they presented for investigation so many remarkable varieties of structure, and seemed to indicate so clearly that they had once belonged to real living organic beings, that the study of "*fossils*" (this term in time becoming limited in its meaning to fossil organic remains), ceased to be the pursuit of curiosity hunters; and it was admitted that the objects in question must be the remains of the former inhabitants of the world, buried during the lapse of ages in those various deposits of mineral matter of which the earth's crust is chiefly composed.

Thus arose the department of zoology and botany which is now called *Palæontology*. It has been alluded to in preceding chapters; and it appears from it that as a certain order of arrangement or distribution of animals and vegetables can be traced on the earth,—different districts having peculiar climates, and distant places similar climates,—so there exists a distribution of life in time almost exactly corresponding with this distribution in vertical and horizontal space.

The discovery and careful examination of large groups of the shells and other remains of marine animals in various deposits of sand and limestone, has long since confirmed this conclusion, which, however, is very important, as marking an era in the history of fossils.

Palæontology, then—a discourse concerning ancient beings—involves the investigation of all that can be known of the plants and animals of the ancient world. Laying aside all speculative or theoretical views concerning the earth and its history, thus much is certain. The earth, as far as we can examine it, consists of various mineral substances—sandstones, limestones, and clays—ranged in strata, in pretty regular order, but often tilted up, so that by travelling across them in a certain direction we find one after another at the surface. Each one of these beds we may regard as being remarkable for some group or other of organic remains (*fossils*), and such fossils afford the only means we have of learning the conditions under which that particular bed was deposited, and the representative forms of that portion of geological time.

If the distribution of species in time, as in space, were not a law of nature, we should soon discover it by identical species in beds of the same mineral character at various depths without such species occurring in the intermediate deposits. In other words, and remembering what has been said of representative forms, we should expect to find identical species in beds above and below those which contain representative species. This has never yet been done, and as many thousand species have been examined and carefully described from a vast number of distinct beds, the law may be regarded as established.

But if this is so—if Palæontology is in a state to command attention as a science dealing with admitted facts and established laws, and may thus take rank as a distinct and complete department of general natural history, there result some inferences and consequences equally startling and suggestive.

Thus it would seem that by the aid of Palæontology all the gaps and deficiencies that occur in the grouping and classification of animals ought to be filled up. Palæontology and general natural history (zoology and botany) together, ought to supply every link, and either form a perfect chain or prove that there is no such thing in nature.

So, again, it might be expected that we should be enabled to determine the peculiarities of climate that prevailed on the earth during the existence of certain groups of animals and plants in any district.

While the climate of the earth and the broken links in creation thus seem likely to be made out by the pursuit of Palæontology, a knowledge of the depth and temperature of the ocean, and some idea of the nature of its bottom during the deposit of any particular stratum, may also be looked for. In a word, a real and unbroken history of nature in her operations through the organic and inorganic world would seem the only limit to this comprehensive branch of science.

Perhaps, at some future day, when observations shall have multiplied and generalisations have kept pace with their increase —when the vast tracts of land, now unexamined geologically, shall have been ransacked for fossils, and all the accumulations of evidence have been weighed and distributed, each having been allowed its fair value in the discovery of truth, something of this kind may occur. Meanwhile it must be admitted that the evidence, perfectly to be depended on as far as it goes, is yet very limited in its range—the blanks and intervals between strata and species are far greater and more frequent than might have been hoped, while the continuity of the so-called chain is by no means proved.

It will be clear that there are two aspects in which we may regard Palæontology. On the one hand, collecting and arranging the varieties of specific character presented by the lost races, we may construct, as well as circumstances admit, a series of groups of species, each corresponding to a presumed period of the earth's history, regarding each of these periods as a region in which characteristic species seem to have originated. Such a region is, in technical natural history language, a *specific centre*, or a point from which species have diverged. The whole earth is considered, according to this view, to be parcelled out at present into a number of districts, each of which is a *specific centre*, and each such district must be supposed to have commenced its biological history by having no species except those created expressly for it, or, in other words, all the prevailing types must have been introduced by an express act of creation.

Such instances of natural provinces are found in the European seas. Six such provinces are described as belonging to these seas only, and a province is understood to mean an area within which there appear to have been called into being the originals or protoplasts of certain animals and plants. In the course of diffusion, and through the lapse of time, species may become extinguished in their original centres and remain only in some one or several portions of the area over which they afterwards became diffused; and as groups of individuals of a single species may thus become isolated, they may present the fallacious aspect of two or more centres for the same species. To get at the causes of such phenomena we must trace the history of the species backwards in time, and inquire into its connexion with the history of geological change.

Provinces, also, like species, must be traced back to their history and origin in past time, and palæontological research obtains for us a knowledge of groups occupying the same geographical position, but changed from time to time and corresponding to groups of organic beings occupying different regions in space. Such is one of the aspects under which Palæontology may be regarded.

But this is not the only view. As the comparison of species living in distant countries with similar climates, or in seas immediately adjacent but separated by an impassable barrier, shows indistinct groups of species in these different localities, not less does the comparison of typical forms under such circumstances show a relation of analogy, if not of affinity. A common bond of brotherhood appears to unite the various families of one province, however distinct they may seem; but a bond of cousinship only—a mutual relationship to the same distant ancestor—is the link that unites races separated by impassable barriers. Looking back far into time we find that the same rule holds good. The resemblance is of one kind when the succession is made out in any given spot by the comparison of species in beds successively deposited; but of another kind when we examine contemporaneous groups separated by wide intervals of horizontal or vertical space.

Let us illustrate this by a few examples. No two marine faunas are more distinct—there is hardly a fish, shell, or crab in common—than those of the eastern and western shores of South and Central America; yet these great faunas are separated only by the narrow but impassable Isthmus of Panama. Further west in the eastern islands of the Pacific, separated by a wide, open ocean, is another and totally distinct fauna. All these are in the same latitude and under corresponding climates, but they are totally distinct. Similar illustrations might readily be given in abundance, but one is sufficient.

Just so it is in tracing back the history of organic beings in time. By the study of Palæontology the law of geographical distribution as deduced from existing species is shown to have been in force during periods of time long antecedent to human history or to any evidence of human existence; and yet in relation to the whole known period of life-phenomena upon this planet, to have been a comparatively recent result of geological forces determining the present configuration and position of continents.

Hereby Palæontology throws light upon a most interesting branch of geographical science—that, namely, which relates to former configurations of the earth's surface, and to other dispositions of land and sea than prevail at the present day.

Finally, Palæontology has yielded the most important facts to the highest range of knowledge to which the human intellect aspires. It teaches that the globe allotted to man has revolved in its orbit through a period of time so vast, that the mind, in attempting to realise it, is strained by the effort. So it is when we attempt to conceive the space dividing the solar system from the most distant nebulæ.

Palæontology has shown that, from the inconceivably remote period of the deposit of the Laurentian rocks, the earth has been vivified by the sun's light and heat, has been fertilised by refreshing showers, and washed by tidal waves; that the ocean not only moved in orderly oscillations, regulated as now by sun and moon, but was rippled and agitated by winds and storms; that the atmosphere, besides these movements, was healthily influenced by clouds and vapours rising, condensing, and falling in ceaseless circulation. Under these conditions Palæontology demonstrates that life has been enjoyed during the same countless thousands of years, and that from the beginning with life there has been death. The earliest testimony of the living thing, whether coral, crust, or shell, in the oldest fossiliferous rock, is, at the same time, proof that it died.

At no period does it appear that the gift of life has been monopolised by contemporary individuals through a stagnant sameness of untold time; but it has been handed down from generation to generation, and successively enjoyed by the countless thousands that constitute the species. Palæontology further teaches, that not only the individual, but the species, perishes; that as death is balanced by generation, so extinction has been concomitant with the creative power, which has continued to provide a succession of species; and furthermore, that as regards the various forms of life which this planet has supported, there has been, on the whole, an advance and progress.*

But Palæontology has not taught the law according to which species have been successively introduced; and as the operation of the introduction of new species is veiled from our eye, except, indeed, it can be traced in the gradual departure of varieties from the type of the species, it is difficult to imagine in what way this mystery will be penetrated.

Naturalists owe to Mr. Darwin, in his work "On the Origin of Species," a fearless and honest induction in reference to this subject. Mr. Darwin, having observed the extreme variability of certain species of domesticated animals and cultivated plants, connected these facts with the great struggle for existence, which results from the command of nature to increase and multiply. The only check on an increase so large and so rapid that any one species would speedily occupy the space provided for all, is a destruction of the weakest and least vigorous individuals.

It is not difficult to follow out this train of argument. A species of animal or plant abundant in any particular locality is so because circumstances are favourable for its development and not so favourable for others at hand that would replace it if they could. There is, however, no permanence in existing things, for no two seasons are exactly alike. Cold and heat, wet and dry, shelter and exposure, all vary from year to year; while a slight change in almost any of these may, in a thousand indirect ways, affect any species. Every species, therefore, must be subject to occasional crowding out, producing starvation, if it be not to some extent capable of adapting itself to changing circumstances. If it should not be thus far capable of change, either in itself, or in some of its offspring, it can only be abundant for a short time, and will then be lost altogether. If it be changeable in any important respect, or if, of the rising generation of plants or animals of any species, some individuals are more readily altered, or are naturally more modified in a favourable direction, than the rest, then there will be the commencement of a variety formed by the accidental peculiarity of some one member of a group. Owing to the well-known law of resemblance of the offspring to the parent, there will probably be some of the next succession who possess this peculiarity of the parents, whatever it may be. Out of the whole number, those individuals who are strongest and best able to fight their way must succeed, and the rest fail and die, being beaten in the battle. If, therefore, the peculiarity is advantageous, it will be perpetuated; if unfavourable, it will be lost.

---

* Owen's "Palæontology," pp. 2, 3.

It is, of course, a most important inquiry how far this production of a variety can go, and what it leads to. As far as man is concerned, he can only take advantage of what he sees, and his selection of peculiarities from which a permanent variety can be secured, is confined to a few external characters. His object, also, being generally to produce modifications which the animal in a state of nature would not be able to sustain, it cannot be regarded as rendering the employments of the method of selection by nature less probable, that known varieties, produced by domestication and cultivation, have a tendency to die out, or even to fall back towards the original type. There is, indeed, no proof that the actual original would, in such cases, be obtained; but the natural varieties of domesticated animals run wild are, as might have been expected, such as point to the peculiarities of structure adapted to freedom and not restraint, and are apt to imitate very closely the peculiarities of structure of the original wild parent.

The principle suggested by Mr. Darwin as the one adopted by nature to produce, first, permanent useful varieties; then species; and afterwards, perhaps, wider divergences, is the principle of *selection*. This word is meant to express the method according to which, in the great battle of life and struggle for existence and supremacy, a balance is always and everywhere struck, and that never-ceasing variety is preserved, which is one of the most striking illustrations of the infinite power and wisdom of the Original Designer.

It would seem to be a direct result of the incessant struggles taking place, that there is so much order and system in nature, and that every race is continued by those individuals who are best adapted to the circumstances of the day, whatever they may be. And it is in this way that we find preserved in harmony the grand scheme of creation, according to which life is everywhere present, and is always tending to higher forms of development where circumstances are favourable. There is nothing in this view of the method of creation that can be regarded as derogatory to the power and dignity of the Great Creator; for, the gradual derivation of species from varieties, under the action of a law imposed on organisation, is as great an exhibition of power as the occasional infraction of a law, or the constant recurrence of special acts of creation.

Let us now rapidly glance at the succession of organic beings on the earth, so far as is made known by the remains that have been handed down for our examination.

The remains of vegetation found buried in rocks include all parts of plants, such as stem or trunk, roots, branches, leaves, flowers and fruit. Remains of this kind occur in rocks of all ages, though they are chiefly abundant in those of the carboniferous period, where are enormous deposits of coal, derived from accumulations of vegetable matter. They include all the known kinds of plants, though in a proportion very different from the present, and it is certain that the same great types of vegetation have always existed from the time when the oldest known plant-bearing rocks were accumulated to the present day. The earliest rocks containing fossils of this kind are the Cambrian, and the remains are those of marine plants. Land plants are known in rocks of the Silurian period.

The most abundant remains of ancient vegetation at all recognisable, are the leaves, or rather the fronds of ferns. These are certainly forms more easily preserved than many others, but they may probably indicate a greater abundance of plants of that kind than now exists, except in some of the islands of the southern seas. Ferns and club mosses, cycads and coniferæ,—these are the abundant kinds, especially in old rocks. In the more modern deposits in which plants occur, there are abundant indications of trees resembling those of Europe at present.

But the extinct species made known to us by the fragments of plants in the coal measures, are not at all like those with which we are now familiar. They include several very curious forms. Ferns and fern-like plants are especially abundant; but remains that seem to be those of gigantic club-mosses and huge reeds are even more characteristic. The *Lepidodendron* and the *Calamites* are the names by which these are known to geologists. The *Sigillaria* and *Stigmaria* would seem to have been the trunks and roots of lofty tree-ferns.

The Lepidodendron seems to have been a form intermediate between the conifers and the lycopodiaceæ, (club-mosses.) The leaves were arranged as in the pines; the branches bifurcate like the club-mosses. The club-mosses are now always minute, but trunks of lepidodendron have been found indicating trees 50 feet high. The leaves, and even the fruit, which is cone shaped, have been found frequently with the trunk; the stem of the tree had a thin cuticle, a double cellular zone, a hollow vascular cylinder, and a pith. The tissue is arranged like that of ferns. Besides this transition form, true conifers, resembling the Araucaria, or Norfolk Island pine, have been found in the coal measures. Some specimens are at least 70 feet long. The Sigillaria was probably a tree-fern, sometimes consisting of a stem 100 feet high, crowned with its tuft of fern-like fronds. It had some relation to the conifers. The roots of these plants were large, and gave off an enormous multitude of branching fibres, extending often 20 or 30 feet. Besides them, there were palms and cycadeæ growing abundantly.

At a somewhat later period, these trees were followed by others, more closely approximating to the modern zamias and cycads. Such plants existed during the deposit of all the secondary rocks, and replaced the older forms. Many examples are found, not only of the fronds, but also of the woody masses which are characteristic of this kind of vegetation, and they clearly take the place of and represent the sigillaria and other trees of the coal measures. With them we find coniferous trunks and stems, and fruits, apparently of palms. All these belong to northern and central Europe, and occur in secondary rocks of all ages terminating with the chalk.

The tertiary period is also well marked. The Cycadeæ were then gone, and were replaced by trees much more resembling those of our own forests, but mingled, even when found in England, with leaves and fruits of palms, and of many plants and trees now confined to the warm regions of the Indian Archipelago. Algæ and marine plants abound, but there is distinct and unmistakeable proof that a close approximation was made to the existing forms of vegetation, even at the time when the older tertiaries were deposited.

The identification of plants by the fragments that are found in a fossil state is not easy or satisfactory, and we can at best obtain a doubtful opinion, in most cases, from the most accomplished botanists. Still, it seems certain that the tribes of plants chiefly accumulated to form coal, and those leaving their mark most clearly in the sand-stones and clays between which the coal is found, were peculiar and characteristic, indicating a condition of things worthy of careful study.

Passing on now to the animals, let us first take those of comparatively simple organisation. Of these, there is a large group called *Protozoa.* They are simple in structure, consisting of a repetition of similar cells, often secreting carbonate of lime or silica from water, and not unfrequently superadding a horny integument. The common sponge of commerce is not a bad illustration of the kind of skeleton such animals possess; but it is only one of many forms by no means all alike. Of the sponges, the remains of species secreting limestone abound in the rocks of the secondary period, especially the oolite and chalk, while the species living now are chiefly horny. As, however, the horny sponges secrete silica, and the horny parts would readily decompose, while the siliceous spicules are very minute and easily injured, this may involve a false conclusion. The sponges are for the most part without regular form, and they are now known to be more widely distributed in a fossil state than they were at one time supposed to be. The celebrated fossil locality of Blackdown, the beds at Warminster, the Kentish rag, and the greensand of Farringdon, in Wiltshire, are all rich in these remains; and some of gigantic size are occasionally found with chalk flints in the upper members of the chalk formation.

Those remarkable shells, long known as *Foraminifera,* consisting of numerous cells coated with carbonate of lime, and communicating apparently by small orifices, are infinitely abundant in some deposits. They are also found in deep sea mud. It is impossible to exaggerate the variety of form presented by these little shells, most of which are microscopic. Large beds, covering thousands of square miles, are made up of single groups of species, and they range from the carboniferous limestone to the existing period. On form, referred to this group, has even been detected in some of the oldest stratified rocks known, certainly much older than the earliest Cambrian rocks of the British islands. We have alluded to it already in a previous page. The limestone of which much of Paris is built, is a mass of these remains; the Pyramids of Egypt are built of them; and they are found in the West Indies. Mud from the bottom of the Atlantic, at a depth of two miles and upwards, over a space measuring 1,000 miles in longitude by 600 in latitude, consists of nine-tenths, by weight, of similar remains; and in the Pacific and Antarctic Oceans, an almost equal proportion of the mud seems to consist of flinty carapaces of animals very closely allied. Dr. Hooker mentions a deposit of this latter kind 400 miles long by 120 broad, and of great and rapidly increasing thickness. Siliceous remains of the simplest forms of plant-life are also exceedingly abundant, and form beds of sensible magnitude, although it requires a good miscroscope to be able to distinguish the smallest trace of organisation, on account of their exceedingly minute proportions.

Many hundreds of species of each of these different kinds have been named; but it may be hoped that some day or other the law of their variations may be detected, and we may reduce to a small group the actual named species.

It is the universal opinion of the best microscopists that some species of these animals range through a long series of deposits, and also through wide space in a living form. It may be assumed that the power that has admitted of the range in time may also account for the range in space.

Of the invertebrate animals of more complex structure, a very large proportion are represented in the various deposits, and, indeed, there are none possessed of any hard skeleton or covering without some examples in many geological periods. There are, indeed, some so uniformly soft, and decomposing with such extreme rapidity, that we cannot hope to see them preserved. Of this kind are the so-called sea-anemones, and some of the true polyps. Of the latter the specimens can only be made to retain their characteristic appearance for a very short time, so that we can only guess at the possible originals of the fossil species.

The *Graptolites* (among the earliest fossils known) are of this kind, and are now represented by the sea-pens. They are abundant in the oldest rocks, not only throughout the British Islands, but wherever such rocks recur.

With the Graptolites, and with almost all the limestones of all ages, are found stony corals. Of these, some are large, and construct gigantic reefs; others are minute, and gradually fill up pools surrounded by the more hardy individuals. There is a marked difference between the stony corals of the different periods. Upwards of a thousand extinct species have been described, and more are being added every day.

The *Bryozoa*, a class of animals intermediate in some respects between the polyps constructing ordinary coral, and the mollusca, who, for the most part, construct shells, are as widely distributed as either. They are compound animals, building singular and complicated habitations. These are of extreme beauty, and generally of small size. The number of extinct species is even greater than that of the true corals.

Star fishes, sea urchins, brittle stars, encrinites, and other singularly formed animals, are referred to the class of *Radiata*. The "stone lilies," occasionally met with on our coast, formed an important group in ancient times. The *Briaræus*, a species of the genus *Pentacrinites*, named from its hundred arms thrown out to collect food, is found in the middle and west of England, and in Yorkshire, and numerous species of other generic forms abound in the carboniferous limestone, and the oolites. Star fishes, though less common, have still a wide range, and sea urchins are distributed at distant intervals in all limestones.

Of each of the tribes of articulated animals:—worms, barnacles, trilobites, crabs and lobsters, and insects—some examples are found fossil in various rocks. The worms, indeed, are known chiefly by their casts, though two or three species provided with a strong coat are to be met with. The barnacles are widely spread, adhering to drift wood in a fossil state, and very frequently to bones and shells. The individuals of one group of these (*Lepadidæ*) were apparently at a maximum in the chalk seas. Thirty-two species of this group are described from cretaceous rocks, and only five are now known in the richest locality for animals of this kind.

A remarkable group of crustacean animals (the *Entomostraca*) pervades the rocks of the older or Palæozoic period. Some of the crustaceans found in the Old red sandstone are supposed to have belonged to individuals who attained a length of seven feet, and many of the others were a yard long. They bear some slight resemblance to fishes, but are more like the king crab (Limulus) of the West Indies. Trilobites are not far removed from them in proportions, but though probably allied, they offer many difficulties in classification. These animals having very prominent eyes, with large lenses made up of numerous facets, long ago attracted attention, as proving that in the most ancient seas the adaptation of the eye to light resembled that now adopted, and indicating that the relation of the sun to our earth, and the state of our atmosphere in regard to light, cannot have greatly changed.

Whilst the marine crustaceans and allied animals have altered considerably, the insects, necessarily almost confined to land, seem very similar, when we compare those of the coal measures and the oolites with those of the present day. Beetles, locusts, dragon flies, scorpions, spiders, have been met with, and though not identical with known species, they are all constructed after the same general plan.

Remains of the shell-bearing molluscs have always been the most common of all fossils, and afford the most characteristic marks for the identification of strata. According to Professor Owen, the duration of types and species as a general rule is proportional to rank and intelligence. Thus, the most highly organised fossils have the smallest range, and mark with greatest exactitude the age of the deposit from whence they have been derived. But the evidence afforded by shells, if less precise, is more easily and constantly obtained, and holds good over larger tracts of country.*

Of the various testacea, the lamp shells (*Brachiopoda*) are in old rocks the most abundant and characteristic, and have suffered most from time. Of 1,300 known and described species, only 75 are now living. The extinct forms are grouped into several genera, some of which are chiefly developed in the oldest or palæozoic strata, while others quite distinct are more modern. The living shells of this group mostly inhabit deep water, and rocky situations not very accessible to the dredge; but they do not appear limited to climate, some inhabiting the sea adjacent to our own coasts, others still more Arctic waters, others, again, the seas of the warmer parts of the Atlantic, and the rest the Antarctic Ocean, and the shores of Australia and New Zealand. Although so widely distributed, however, there are only nine living species of the group now referred to, although more than sixty species are described from a single deposit of the older secondary period. One species of Terebratula from the chalk so closely resembles an existing species that it cannot fairly be separated from it.

---

* Owen, *ante* cit, p. 49.

It is singular that other groups of these remarkable animals are almost equally aberrant. Both recent and extinct forms of *Rhynchonella*, which have no minute piercing of the shell for the passage of tubular spines, and no calcareous skeleton of spiral form to support their arms, have been found all over the world. One of these recent species is in the Arctic seas, another in New Zealand, and a third at the Feejee Islands, while of the 250 extinct species, it would be difficult to say where they may not be looked for. Other forms, again, as *Orthis*, *Calceola*, and even *Producta*, though once extremely common and highly characteristic, are now, and have long been, lost. *Crania* and *Lingula*, met with in the oldest fossiliferous rocks, may be said to have remained almost unchanged in strata of every period, the most ancient fossil shells offering absolutely no important peculiarities to distinguish them from their recent representatives.

Of the bivalve shells, nearly six thousand extinct species are named and described, in addition to about half that number of recent species. These forms of existence, however, would seem to have been gradually increasing in relative importance, as the whole number of described species in all the silurian rocks is less than 100, while the chalk alone contains 500, and one part (the middle) of the tertiary series, 800. Of the genera, again, some have become extinct, some have passed their maximum, and some are altogether modern, but certain amongst them are universal. Thus the oysters, left-handed animals—resting always on the left valve, the scallops (*Pecten*) resting on the right valve, and some curious modifications of both groups are infinitely common, both in a fossil and recent state; and the same may be said of the mussels and the large group of ark-shells, which range through rocks of all ages. The fresh-water mussels (*Unionidæ*) are widely distributed in fresh-water formations, and can hardly be separated from existing genera.

A curious group of animals, inhabiting very thick and massive shells like the recent *chama*, seems to have been widely represented by numerous generic and specific forms in ancient seas, especially those of the lower chalk period (thence called "hippurite limestone"). These are among the most divergent structures, and admit of great modification of form in the same species.

The cockles, universally distributed now in space, are almost equally so in geologic time. Peculiar forms now limited to certain districts are found indicated in the fossils of the same districts, but with a wider range, and a group of allied shells (*Lucina*, *Corbis*, *&c.*, well known to collectors), are equally common in a fossil and recent state.

The boring shells (*Pholas* and *Teredo*, the modern shipworm), exercised their peculiar powers in ancient seas as at present, pieces of drift wood in a fossil state being found with the fossil remains of the extinct boring shells embedded in them. These have not been found in beds older than the lias.

Fossil univalves are spread quite as widely in the rocks and strata of various age as the bivalves; but while the extinct species are about the same in number as those of bivalves (6,000), the recent species exceed 8,000. It would appear, therefore, at first, that the group of univalves was of more modern introduction and later in attaining its maximum.

The air-breathing or land animals provided with shells (snails, &c), figure so very highly in the lists of recent species as to amount to one-half the whole number. While, therefore, the number of extinct species of land shells is comparatively small (only about 450), as must have been the case from the far greater facility with which the marine species would be obtained for accumulation in aqueous deposits, it results that the number of extinct and recent species of marine univalves is about the same.

Although the univalves, as a group, are more highly organised than bivalves, and ought therefore to be more strictly determinable, there are great practical difficulties in this respect, owing to the slight relation between the shell and the animal, and the tendency of the shells to become thickened and coated in various ways when the condition of the water, with regard to transparency and quiet, is seriously altered. Thus, the shells inhabiting disturbed water are generally thicker than those of the same species in calm water, and this thickness is apt to affect characteristic peculiarities of structure. On the whole, however, the older species are found, on close examination, to differ from ordinary recent types, and the nearest allied forms are to be found among the more minute and rare recent species.

A group of shells like the *Argonaut*, unprovided with walls or air-chambers, is found in palæozoic rocks, and these probably represent the *Heteropoda* now living. The shells, however, of the extinct species are far thicker and clumsier. The strombs which, in spite of their massive shells, are among the animals that approach the delicate and fragile Heteropoda in structure, extend only to the oolites, while the whelk tribe, by far the most important of living sea shells, are only represented in the older tertiaries. Cones, volutes, and cowries, now chiefly confined to warmer waters than those around our shores, are common amongst us as cretaceous and tertiary fossils, and the same may be said of the large groups including the limpets (*Patella*), the tooth shell (*Dentalium*), the top shells (*Turbo* and *Trochus*), and the telescope shells (*Terebra*).

But it is chiefly the *Cephalopoda* whose remains are characteristic of the various deposits, from the most ancient down to the chalk. Comparatively rare now, at least in our own seas, we find indications of no less than 1,400 extinct species to place against the three or four to which the recent lists are limited.

The *Ammonite*, *Hamite*, *Turrilite*, and *Baculite*, are nautili with the shell straight or twisted more or less completely, and with the septum or wall of separation between the air-chambers making a more or less zig-zag intersection with the shell. These are the forms found everywhere in secondary rocks. *Orthocera*, and other straight and more directly nautiloid forms, characterize the older rocks, and the intermediate *Goniatite*, perpetuating through life the early development of the ammonite, marks the passage from one to the other.

Siphuncles (the tubes passing through the chambers) as much as 6 feet in length and 1⅛ inch in diameter, mark the gigantic proportions to which the orthoceras reached in the silurian limestone at the earliest stage, and huge fragments of turrilite from the chalk prove that no degeneration had taken place in this respect after the lapse of so long a period, and when the reign of shelled cephalopods was drawing to its close. The secondary rocks contain five hundred species of ammonites, some as large as the wheel of a carriage, and they range not only throughout Europe, but in many parts of Asia, Africa, and the two Americas.

Besides those provided with defensive armour, the naked and soft cuttle fish, poulpes, or calamaries seem to have been present in incredible abundance. Complete specimens have been found not rarely in some of the clays, while the curious pen, the ink-bag, the horny claws, the mandibles, the mantle, and, in fact, the complete mummy of the animal have been preserved, and are occasionally collected. Among the most common remains of these animals is the stony *Belemnite*, a well known cylindrical fossil, having one extremity pointed and slightly conical, and terminating upwards in an open funnel-shaped cavity. The whole of this fossil represents the white *cuttle-bone*, often picked up on our shores, which serves as a skeleton for the attachment of the muscles of the cuttle fish.

Such, in a few words, are the fossils of the invertebrate classes, as at present known. Those of the vertebrata we must next consider, but before concluding this brief outline concerning the animals of lower and less complex organization, we quote a significant remark by Professor Owen, that "every type of invertebrated animal is represented in the stratified deposits called Cambrian and Lower Silurian,"*—in other words, in the oldest of all those rocks in which organic remains have hitherto been found.

It is not to be denied that this fact of the almost universal distribution of invertebrate types throughout the oldest rocks, and the absence of any fossils in the large group of little altered sedimentary deposits occasionally found beneath them, offers grave objections to Mr. Darwin's view of the case. He is, however, aware of the difficulty, for we find him remarking that if his theory be true, "it is indisputable that before the lowest silurian stratum was deposited, long periods elapsed,—as long as, or probably far longer than the whole period from the silurian age to the present day; and that during these vast, yet quite unknown periods of time, the world swarmed with living creatures."

---

* Owen's Palæontology, p. 96.

He then proceeds to remark:—"To the question why we do not find records of these vast primordial periods I can give no satisfactory answer. . . . . The difficulty of understanding the absence of vast piles of fossiliferous strata, which in my theory no doubt were somewhere accumulated before the silurian epoch, is very great. If these most ancient beds had been wholly worn away by denudation, or obliterated by metamorphic action. we ought to find only small remnants of the formations next succeeding them in age, and these ought to be very generally in a metamorphosed condition. But the descriptions we now possess of the silurian deposits over immense territories in Russia and in North America, do not support the view that the older a formation is, the more it has suffered the extremity of denudation and metamorphosis."

Mr. Darwin states his belief that, after all, the imperfection of the geologic record is the real cause of the existence of this apparently grave objection; he regards this record "as a history of the world imperfectly kept, and written in a changing dialect; and of this history we possess the last volume only, relating to two or three countries. Of this volume but here and there a short chapter has been preserved, and of each page only here and there a few lines. Each word of the slowly changing language, in which the history is supposed to be written, being more or less different in the interrupted succession of chapters, may represent the apparently abruptly changed forms of life entombed in our consecutive but widely separated formations."

But while the remains of invertebrata are abundant and distinct, even in the oldest rocks, it is still a matter of discussion whether fragments of fishes were or were not always associated with them. We know, indeed, that the teeth of some species of fishes occur in the rocks of the later silurian period, and prove the existence at that time of true vertebrate animals. These have been found in a well-known deposit near Ludlow. One of them belonged to a kind of dog-fish or small shark, and the other to a representative of a singular group of ancient fishes, provided with enamelled, bony plates, locked together, and occupying the place of ordinary scales, which overlap each other. There is nothing whatever in the structure of these fishes to intimate that they were the earliest forms introduced on the earth.

The spines of these early inhabitants of the sea are two inches in length, and are found with petrified portions of the skin, which are tubercular and prickly, like shagreen, and also with the rejectamenta (*coprolites*) of fishes, containing undigested portions of food, including recognisable parts of the small molluscs and crinoids which inhabited the sea-bottom in company with the fish. Other remains, resembling jaws with teeth, are still considered doubtful, and the combination of jaws and teeth of the kind they resemble, with the spines and shagreen of the dog-fish, would be a combination of characters not elsewhere known.

The apparent commencement or original introduction of any form of life is and must always be a matter of extreme interest to the naturalist; and we are tempted to inquire whether the negative evidence concerning the absence of fossil fishes in the oldest deposits is sufficiently based on large observation to justify us in asserting that they first appeared in later formations. The argument in favour of this conclusion is thus stated by Professor Owen:—"No detached teeth, unequivocally referable to a plagiostomous genus, nor any true ganoid scales of a fish have yet been found in the formations that have revealed these earliest known evidences of vertebrate animals. What, then, it may be asked, were the conditions under which so immense an extent, as well as amount, of sediment was deposited—including chambered cephalopods, gasteropods, lamellibranchs, brachiopods, various and large trilobitic crustaceans, with crinoids, polyps, and protozoa—that precluded the preservation of the fossilizable parts of fishes, if that class of vertebrate animals had existed in numbers, and under the variety of forms, comparable to those that people the ocean at the present day? Bonitos now pursue flying fishes through the upper regions of an ocean as deep as any known part of the silurian seas, of which the deposits afford an idea of greatest depth. If fishes of cognate habits with the present deep sea fishes, under whatever difference of form such silurian fishes may have been manifested, had really existed, we might reasonably expect to find the remains of some of the countless generations that succeeded each other during that vast and indefinite period sufficing for the gradual deposition of sedimentary beds of thousands of feet in depth or vertical thickness. The best reply we can give to this argument is a simple statement of the fact, that where we know that the upper water abounds with various forms of animal life, still, in all the material as yet obtained and examined from a deep-sea bottom, hardly a single instance has occurred in which any fragment of a highly organised animal appears. All is organic; but all belongs to the simplest forms of organic existence."

The group of plagiostomous fishes to which the species above alluded to belongs, is one of considerable interest, both for its living and extinct representatives. It includes the sharks and rays, two distinct but allied natural groups. The former are remarkable for fins provided with hard, defensive spines, the action of which is connected with the use of the fin, being lifted up or lowered during the peculiar rotary motion of the body of all the shark tribe, and also serving as a weapon. In the case before us, the spine, two inches long, which must have belonged to a dog-fish of moderate size, indicates, at the same time, the existence of another larger fish, the natural enemy of this, and against whose attacks the weapon was provided. No remains of such larger animal have yet been found.

Spines of sharks and rays are found in rocks of various ages. They are generally grooved and often toothed in the older rocks. This denticulation is sometimes seen on both sides of the spine, a structure not now met with, except in one family of rays, so that it is possible that sting-rays, as well as sharks, abounded in seas of the carboniferous period. The dimensions of the spines increases in the secondary rocks, and in the lias they have been found very large. They are throughout abundant fossils.

With such spines have been found the peculiar teeth belonging to a family of sharks now only met with on the coast of Australia and China, and known as the Port Jackson sharks (*Cestracionts*).

There are now only two or three species of these animals, and the group seems approaching extinction. It formerly flourished under a great variety of forms, represented by species some of which attained dimensions far exceeding the largest known living cestracionts.

The teeth of these animals is peculiar, and especially adapted to the taking and masticating crustaceans and shell animals. The animals are of a harmless, timid character, and use their peculiar spines for defensive purposes only. The whole of the inside of the mouth and palate are completely paved with flat, crushing teeth, diminishing gradually in size as they pass back to the throat. This beautiful tesselation is quite unrivalled in fishes or any other animals, although the general contrivance is repeated with various modifications in the hard-boned fishes. It indicates a diet of lower organised animals than those on which the true shark preys, and a corresponding difference of character and disposition. It need not be pointed out that food, consisting chiefly of the lower forms of animal life, or exclusively of vegetation, does not involve a lower or less complex structure than more nitrogenised food.

After the death of an animal the teeth become detached and are readily dispersed, and very numerous varieties of form, no doubt belonging to many species, are met with in almost all rocks, from those of the Devonian period to the present day. In many cases the form is such that its relation to fishes is not readily seen, and fossils of this kind are sometimes called petrified leeches or worms, or are known by other local names. The carboniferous limestone, the lias, and the chalk, have each yielded a great variety of curious forms.

Teeth of true sharks have not been found yet in rocks more ancient than the oolites, but are common there, and much more so in newer rocks. Some of them indicate animals of the largest size and most predatory habits, resembling both the blue and white shark of existing seas. The tooth of a modern shark two and a quarter inches long corresponds to an animal measuring twenty feet in length; but from the middle tertiary beds of Malta specimens of teeth have been obtained more than double the dimensions mentioned, and therefore belonging to an animal perhaps sixty feet long. Teeth of a species very nearly allied, and of the same genus, have been found in the red crag of Suffolk, considerably larger even than this.

Spines, skin-plates, and teeth of more than one of the characteristic forms of rays have been found fossil in every marine deposit from the silurian to the most recent period; but all belong to extinct species. They represent animals of various proportions, but, for the most part, not large as compared with the sharks. The peculiarly flat pavement of teeth of these animals readily attracts attention, and is not, at first sight, recognised; but the extinct do not differ essentially from the recent forms in this respect.

Another nearly extinct natural order of fishes is abundant in a fossil state. A curious fish, known in the northern seas as the "king of the herrings," belongs to this order. It is represented by two species in Chinese and Australian waters, but is otherwise unknown.

Beak-shaped jaws and mandibles, and curious spines of allied species, are common in some of the older rocks, and are the principal remains of such animals preserved, inasmuch as their bones are cartilaginous. Occasionally, however, in ancient times, the soft skeleton of these fishes was abundantly strengthened by an external casing coated with the hardest enamel and formed of plates of various shapes, closely locking into each other. Such boxes of bone plated with enamel have preserved the form of some curious inhabitants of the primeval seas.

One of the most singular of the fishes of this kind is the wing fish (*Pterichthys*), long ago picturesquely described by Hugh Miller. Of all the organisms of the old red sand-stone, one of the most extraordinary is this winged fish, and certainly it is difficult to imagine an animal whose remains are more calculated to excite astonishment.

In this creature the head and half the body were defended by interlocking plates of hard bone, coated with enamel. The plates covering the head correspond in some measure with the cranial bones of fishes, but not exactly. The rest of the body not covered with plates was defended by small scales, flexible like scale armour. The helmet or coating of the head was articulated to the body, admitting of a certain amount of motion—a rare peculiarity in fishes—and there were two long and slender spines proceeding from between the head and neck, also coated with enamel plates.

It is supposed that these spines may have served to aid the fish in shuffling along the sandy bottom or bed of the sea if left dry at low water. There were small fins attached to the flexible part, which indicate a certain though small power of swimming. In a closely allied animal (*Cephalaspis*) larger fins have been observed, and a well-marked capsule of the eye-ball; and in another (*Coccosteus*), the pectoral fins are absent, and the helmet is united to the cuirass.

Strange as seem the forms and structure of these fishes of the "Old Red" period there are not wanting existing species to throw light upon them. The "trunk-fishes," for example, though small, exhibit the peculiarity of possessing a kind of cuirass composed of articulated plates, having tubercles on the external surface prolonged into spines, while the caudal extremity protrudes undefended from the back part of the cuirass. Another existing family, the "Siluroids," have the head defended by a kind of buckler, while the body and tail are undefended.

It seems probable that the carcases of the fishes whose skeletons are so common in these ancient beds were entombed in the mud which now contains the bones, the sand immediately around the specimens being generally bituminised and exceedingly hard. The flagstones of Caithness, useful for various practical purposes, owe their peculiar qualities of density, tenacity, and durability to the dead fishes that rotted in their primitive constituent mud.

Another remarkable group of fishes, having large rhombic scales like those of great reptiles, and belonging to animals attaining gigantic proportions, is characteristic of the coal measures, and has very near representatives in the newer beds. In one of these (*Megalichthys*) the head was defended by strong, bony plates, coated with enamel, of a beautiful polish, but not interlocking. In these, as in all the fishes from old rocks, the vertebral column is invariably continued beyond the body, to form an unsymmetrical tail-fin, a peculiarity now confined to a comparatively small number of existing fish in a grown state, although still observable in the young and rudimentary skeleton.

A singular group of fishes (*Lepidotus*), adapted by their pavement of crushing teeth to feed on small testaceous and crustaceous animals, and resembling in form some of our flat fish, belonged to the same natural division as the fishes we have just been describing, and are chiefly found in secondary rocks. Like them, their scales were coated with enamel, and the tail was generally unsymmetrical, and directly attached to a continuation of the back bone. In some of these the scales have a thick, bony rib, spliced off at the extremity for attachment to the next adjoining scale; and these splices are so closely adjusted as to be invisible without a magnifying power. There are other curious modifications of structure exhibited by these animals.

The sturgeon is the best, or at least the best known existing fish of the so-called *ganoid* order; a name given to this group owing to the peculiarity of the scale, which is bony and coated with enamel. Almost all the ancient fishes, except the sharks and rays, are of this kind.

In the lias is a species of sturgeon, to some extent transitional; its food, however, though similar to that of the existing members of its family, was apparently procured in a tranquil sea rather than in such tumultuous waters as are frequented by the sturgeons at present.

We have no space to dwell on the numerous gradual approximations to existing forms exhibited by the fishes of successive periods. Among the most singular and interesting remains, however, we may mention the "sword" or defensive weapon, more than a foot in length, of a kind of sword-fish, found in the tertiary clay of Sheppey and Bracklesham, and species of turbot and sole are found in the tertiary deposits of Monte Bolca. In other tertiary formations are found fossil cod, mullet, carp, salmon and herring, many of them so closely related to existing species as to be with difficulty distinguished from them.

The conclusions of Professor Owen with regard to fossil fishes are not without interest in reference to the subject of species generally. He considers that a retrospect of their history imparts an idea of modification rather than development; and although the present appears to be the culminating period in their development, it represents "rather a period of mutation of the piscine character depending upon the progressive assumption of a more special piscine type, and progressive departure from a more general vertebrate type." He considers, in opposition to a view once held, that "a higher character of organisation may be predicated of the palæozoic placoids and ganoids, than of the ctenoids and cycloids forming the great bulk of the class at the present day." He also says that "the comparative anatomist dissecting a shark or other fish of the ancient type would point to various structures as being of a higher or more reptilian character than the corresponding parts would present in most other animals, while the palæontologist would discover evidence of an arrest of development or a retention of embryonic characters in the primeval fishes."

No doubt, in many respects, fishes are the most useful to the geologist of all animals whose remains are abundant in a fossil state, for by their aid we compare ancient and modern forms; and the conclusions from such comparison, when honestly and carefully made, cannot fail to be of great value. In this respect the general absence of true development, by which is meant the gradual advance from a lower or simpler to a higher or more complex structure, is a fact well worthy careful consideration. It appears to us, however, that this is in all respects consistent with an adoption of Mr. Darwin's view of adaptation, by a natural method, to existing circumstances, since this method involves no necessary advance in all the species of a group, though one or more species may pass from out of the group and form the commencement of a large series of animals of greatly increased development.

There is a very curious department of palæontology, which it seems convenient to take into consideration at this stage of the subject, inasmuch as most of the remains now to be described are those of animals more or less terrestrial. This department is called *ichnology*, and is intended to include a group of fossils, in which there is indeed no organic matter present, but where there are indications not one whit less certain of former organic existence.

The evidences of ancient life to which we now allude, are, perhaps, best illustrated by what are called "fossil footsteps;" since under this name markings in sandstone have been known for many years, many of which have generally been referred to reptilian animals.

Wherever indeed animals have lived, or physical forces of any kind have acted; at all times, therefore, and in all places, from the commencement of the earth's existence as a planet to the present day, remains may be looked for that belong to the present group. Let us consider for a few moments what such indications are, and how they have been preserved.

A film of clay resisting the escape of a bubble of gas may retain the circular trace left by the collapse of the bubble; a flash of lightning may record its path through soft sand by melting it into glass during its swift transit in search of moist earth; a small wave—a rain-drop—a hailstone—the breath of a wind as it heaps loose sand into ripples—the sudden effect of frost during a clear, calm night—the crack produced by the heat of the sun on a hot day—the little heap of mud left by a worm as it came to the surface or crawled along it; any or all of these may be preserved permanently—may become an integral part of a sandstone, a clay, or a limestone bed then forming, and, like the photograph, may fix for ever an exact image of the most transitory occurrence in nature.

But not only may we have indications of inorganic nature; sea-weeds, including those kinds that decay very rapidly—soft-bodied animals, such as the sea anemone or the medusa—soft parts of the animals of which we also have the skeletons—all these may be preserved; and, besides these, are the impressions made by various animals when moving across sands or mud when the surface passed over was favourably circumstanced for retaining the imprint.

There are many ways by which such impressions may be preserved. Where the tidal wave, entering deeply embayed coasts or funnel-shaped inlets, becomes so multiplied as to rise to a great height at each successive time of high water, there will generally be a great moving about of animals during the intervals; and between each two successive spring tides there will be a long interval, during which large tracts may remain uncovered. If the surface consists partly of micaceous mud and partly of sand, and the weather is fine, with occasional hot sun, the marks made immediately after each tidal wave has left, may be so far baked and indurated during the interval that occurs before the water covers it again, that the returning wave will only deposit a second stratum of mud, which will occupy all the hollows, markings, and irregularities formerly produced with soft matter capable of receiving another set of similar markings, to be in its turn hardened, indurated, and perpetuated. In after times, this rock will split in the planes of deposit, and the mark, whatever it is, will be revealed.

In many ways, thin layers of mud deposited on sands retain permanently the footprints of birds or reptiles, or other animals that wander over the sand in search of food, and follow a receding tide. Sometimes, layers of fine clay deposited between beds of sand, now converted into sandstone, present the most minute representations of the marks impressed upon them; and at other times, clouds of fine dry sand blown by the wind have filled up all the inequalities of surface made on the moistened shore, and are themselves moistened when the water returns.

In the oldest rocks, rain drops, ripple marks, the borings of worms, and the scratchings attributed to small crustaceans or fishes, attest the existence of animal life even where all remains of such animals are absent. But it is by no means easy to determine the nature of the animal from indications of this kind, and the earliest markings are also amongst those most obscure. The earliest of all are thought to have been made by a large crustacean, perhaps a kind of trilobite, but they do not show that side-long motion which characterises the crab. "The imagination is baffled in the attempt to realise the extent of time past since the period when the creatures were in being that moved upon the sandy shores of that most ancient silurian sea; and we know that, with the exception of certain microscopic forms of life, all the actual species of animals came into being at a period geologically very recent in comparison with the silurian epoch."

Belonging to a remarkable genus of extinct reptiles, which is called *Labyrinthodon*, owing to the complicated appearance of a section of the tooth, we find numerous remains in the coal measures of America and in the new red sandstone in many parts of the world. Some of these would seem to have belonged to animals of large size and peculiar arrangement of the organs of locomotion, and they have been considered to form a natural order nearly allied to the batrachians. The head of these animals was very wide, and defended by a kind of helmet of externally-sculptured hard and polished bones; the teeth were large and complex, and the general form must have been something between that of the toad and the land salamander.

No less than five well-marked species of these remarkable animals have been determined from British specimens found in the new red sandstone, and many others are known from continental (European) deposits of the same age. They vary in size and in proportions, and exhibit in some cases striking peculiarities of structure. The bones found are chiefly those of the skull, which show a marked approach to the crocodilean type, though with modifications connecting them with the frogs. The few bones of the extremities that have been examined point, however, in the other (batrachian) direction, though not exclusively. The proportions are very peculiar, as in the case of one group of specimens, consisting of two fragments of a skull and portions of the lower jaws, with bones of the leg, the bones of the head correspond with those of a crocodile six or seven feet in length, and those of the hinder extremities with crocodiles twenty-five feet in length, showing a singular disproportion compared with existing saurians, but an approximate magnitude compared with tailless batrachians. The footprints in the new red sandstone fully justify the conclusion that an animal of this anomalous character really lived during the period of that deposit. Some of the footprints, indeed (originally named *Cheirotherium*, owing to the peculiar hand-shaped appearance of the impression), would seem to have been made by animals very much larger than just described, though of similar proportions, the hinder extremities being exceedingly larger in all respects than the fore legs and feet.

An important conclusion is drawn from the careful consideration of these curious remains. It is, that the supposed class-distinction between fishes and reptiles is artificial, and that all the cold-blooded vertebrata form one unbroken progressive series. Many of the earliest reptiles, known to us only by fossils, and many of the earlier fishes also extinct, are connected together by intermediate gradations, which are so complete as to render it impossible in some cases to determine whether the fish or the reptile is more nearly approached.

Passing on another step, we come to the very interesting group of large-finned reptiles, which, in some respects carries us forwards to the warm-blooded cetaceans, and in others backwards to the fishes. Characteristic eminently of the great secondary period, these animals attained proportions so gigantic, and adapted themselves so completely to perform the part of the whales and other cetacea who have succeeded them, that they have always been regarded as affording strong support to the idea of a gradual development of structure from a lower to a higher type. They have been long familiar, although known only by their remains in a fossil state. These are, however, so perfect as to include even the skin, the contents of the stomach, and the structure of the caudal fin, a soft and easily-decomposed appendage, whose existence and structure are recognised from the position of the vertebral column in the skeleton. In many respects, these are among the most interesting and instructive of all the extinct reptiles. They are now grouped into two orders, the first of which contains only the *Ichthyosaurus* or fish lizard, an animal well known by popular descriptions, frequently repeated and gradually perfected as the specimens of these curious animals have been multiplied.

Few things in natural history are more striking than the minute details we possess of the habits and peculiarities of this animal. Its tail alone indicates the combination of beast-like, lizard-like, and fish-like characters possessed by it; and almost every other bone marks the same fact. The skull, indeed, affords, in its minute anatomy, almost all that could be required; and if only a few vertebræ had remained, there would still have been little doubt as to most essential points.

A considerable variety of marine reptiles, more or less widely departing from the fish type and approaching that of the crocodiles and lizards, are distributed throughout the whole of the rocks of the secondary period. In the oldest of these rocks (the triassic rocks of geologists) are some combining peculiarities of the crocodile and the turtle, while there is one genus, *Placodus*, provided with a pavement of teeth so remarkable and so like that of the Port Jackson shark, or wolf-fish, that the remains were long referred to a family of true fishes. Some of the Australian lizards exhibit the same peculiarity, and the bones of the skull, which alone are known, have established the position of this animal among the reptiles. It must have fed on very hard kinds of food, probably crustaceans and shelled molluscs.

The *Plesiosaurus* is an animal as well and as long known as the ichthyosaur, and both are equally remarkable for the extraordinary abundance of their fossil remains in England, and the singular variety and number of species determined. They range from the lias to the chalk, inclusive. Although singularly unlike in external form, the relations of plesiosaurus to some of the turtles are very marked. The extreme length of the neck, characteristic of some species, is less considerable in others, and in an allied genus (*Pliosaurus*) is reduced to a short, compact, bony connection between the head and trunk. As in other respects the bony frame-work of pliosaurus and plesiosaurus agree, and the former is sometimes so large as to indicate a length of thirty or forty feet, in spite of the absence of neck, it is unsafe to judge of the limits of plesiosaurus, except when we have the complete skeleton before us. The animal was generally slender, and does not appear to have reached a much greater length than thirty feet, judging from the specimens hitherto found.

A modification of these marine saurians is seen in a group of fossils brought several years ago from South Africa, indicating a reptile (the *Dicynodon*) having a long and curved tusk on each side of the upper jaw. The jaw itself was probably beak-shaped, and covered with horn. This curious combination of tusks, like those of the sea-horse, with a horny mandible, like that of a turtle, belonged to an animal of considerable size, the skull of one individual measuring twenty inches in length by eighteen inches across. A more lizard-like animal (*Rhynchosaurus*) provided with similar mandibles, though without the tusks, is known from some English beds of the new red sandstone period. In slabs from the same quarry as that in which these bones were found were numerous foot-prints, supposed to have been made by this creature, but greatly resembling the impressions that would be made by a bird. The feet of the unknown animal were partly webbed, and one hind toe touched the ground with its point.

A still more bird-like saurian than the Rhynchosaurus was the *Pterodactyl* or wing-finger, one of the most remarkable of all the reptilian animals hitherto described, whether in recent or fossil state. Like many other reptiles, these animals belonged exclusively to the secondary period, and seem to have ranged through that period, although with different species. The head was large, with long jaws, armed with sharp pointed teeth, and the skull was lightened by large vacuities. The long bones were light, hollow, and permeated by air-cells. The back was small and weak, and the hind limbs and pelvis weak, so that the creature could not have stood or walked like a bird, but must have dragged along the ground like a bat. But the fore extremities are wonderfully developed, the fifth or outermost digit or finger having been so greatly elongated as to mark its use for flying. No doubt, a large and strong membrane extended from this elongated finger to the body and tail, including the hind extremities. The pterodactyls were probably powerful swimmers as well as flying animals.

Most of the species were small, but some from the greensand and chalk appear to have attained very gigantic proportions, the expanse of the wings reaching to eighteen or twenty feet.

A group of gigantic reptiles, some carnivorous and some herbivorous, characterised the land of the secondary period, and their remains are sparingly distributed amongst such deposits as were sufficiently near shore to accumulate terrestrial organisms.

In some peculiarities of dentition, the *Megalosaurus* of Dr. Buckland approaches the structure of the higher mammals, and the teeth afford a singular combination of cutting and sawing implements. This animal, like the other gigantic land reptiles of the period, was supported on four strong and tall limbs, terminated probably with claws. The bones of the extremities were hollow, and some of the remains indicate an animal thirty feet in length, and of a height proportioned rather to that of the elephant than the crocodile. The bones of the megalosaur and an allied genus are found in the lower parts of the oolitic series and the lias, but another reptile of similar proportions, though less completely carnivorous, occurs in the wealden beds, together with fragments of a purely herbivorous giant very nearly allied. The latter (*Iguanodon*) has generally been compared with the large iguanas still living, though the relations, except in the peculiar structure of the teeth, are not clearly indicated.

Crocodiles, and crocodilean reptiles, seem to have existed from the deposit of the old red sandstone to the present time, and several of the peculiar varieties of form in which they are still found are represented by very ancient extinct species. Thus, the alligators or caimans, the gavials, and the true crocodiles, are all seen in very old deposits. In former times they were probably as abundant in the waters and swampy lands that then occupied the sites we inhabit, as they are at present in the swamps at the mouths of all the great tropical rivers. Lizards and other reptiles, some of gigantic size, lived during the deposit of the chalk, and smaller kinds must have been at all times common.

Remains of serpents are less frequently found, as being rarely likely to mix with water-formed deposits. They are, however, not absent in the newer rocks, though hitherto unknown in those of the secondary period. Tortoises and turtles belong both to the secondary and tertiary period, and many curious varieties of form are shown. One tortoise of very gigantic proportions lived in India during the middle tertiary period, its carapace measuring no less than twenty feet in length.

On the whole, it is concluded by Professor Owen that the class of reptiles, unlike that of fishes, is now on the wane, having been chiefly abundant during the middle of the three great geological periods. It was then that the colossal air-breathing species, having the highest grade of structure and the most marked peculiarities and modifications, seem to have lived. Their progress has since been checked; other air-breathers of higher types have replaced them, and they have been driven out by other tribes which they both typified and represented. Of eight great divisions of the class, three are altogether gone; and of the other five, three only can be regarded as having in recent times their chief development, while important natural families in some of these have passed through all their stages, and finally disappeared.

The earth is now peopled with mammals, and the air with birds, while in the sea the whales take place of the ancient reptilian monsters. Of all that remain, the tortoises and turtles, the crocodiles, the lizards, and the frogs, offer analogies enabling us to comprehend the peculiarities of the extinct forms, but in comparatively few instances do they represent forms truly analogous. Most of the representatives of these remaining natural groups are comparatively small, and occupy a lower relative place in creation than they once did.

Birds, as we have seen, are known by their footsteps in the most ancient rocks. Nor can it be wondered at that these indications are present even without bones or other actual organic remains. For the most part, birds inhabit land, or at least visit the land constantly, and their bones would, for this reason, be less likely to occur in sedimentary deposits than the bones of fishes or aquatic reptiles. There is, indeed, no difficulty in the preservation of the bones when once embedded; but it is evident, from their great rarity, that circumstances have seldom been favourable for their deposit.

The footsteps of birds are peculiar, and are more readily distinguishable than those of most animals. Birds tread only on the toes; these are jointed to a single bone at right angles to it, and the toes diverge more from each other, and are less connected with each other than in other animals. With few exceptions, only three of a bird's toes are directed forward, the fourth being shorter, and directed backward, taking less share of the weight. Guided by these analogies, Dr. Green, an American naturalist, announced so long ago as in 1835 the existence of a bird that had lived during the new red sandstone period, and whose dimensions, judging from the size of the impressions, were at least four times as large as those of the ostrich. The footprints are twenty inches long, and the average stride between them more than three feet. The marks of the gigantic feet that trod this sandstone while it was yet soft mud are singularly well preserved, showing even the markings on the cushions on the under side of the foot. The animals seem to have been gregarious, many parallel rows being sometimes seen a few feet apart.

The rocks in which the sandstones are found, which are thus characterised, must have been formed in shallow water near shore. The tracks have been found in more than twenty places scattered through a district measuring nearly eighty miles from north to south, and are repeated through a succession of beds more than a thousand feet thick.

No other proof of the existence of such animals is wanting, and no other has yet been found in the new red sandstone. From the oldest to the newest of the secondary rocks, the only other indication of birds consists of a part of a toe bone of a species about the size of a woodcock.

The extreme caution with which negative evidence in this particular department of science requires to be treated could not be better exemplified than in the case before us. In the whole of a long and remarkably well-developed series of deposits, containing not only remains of marine animals in abundance and perfection, but complete insects, the soft parts of molluscs, minute bones of quadrupeds not larger than a rat, the most delicate parts of trees and plants, and indeed all kinds of fossils apparently the most unlikely to be preserved, we have as yet discovered no proof of the existence of birds, beyond a few footprints in one of the oldest, and a few toe bones in one of the most recent deposits. Doubtless, this slender basis is sufficient to enable us to fill up in idea the intervening period; but how accidental is the discovery of these two isolated facts, placed at the two ends of the geological series!

In tertiary rocks a few other birds' bones have been found, and their footprints have been suspected in carboniferous rocks. These latter are still disputed. The former mark a gradual approximation to existing conditions.

Very remarkable in every respect are the gigantic bird's bones discovered some years ago in New Zealand, and since described under the name *Dinornis*. Such birds might, no doubt, have made footprints like those found in the new red sandstone, but they belong to deposits so modern that there is a shrewd suspicion of some individuals, at least, having remained in the islands till they were peopled by man. New Zealand is not more remarkable for the absence of large quadrupeds than for the presence of the living *Apteryx* and the extinct Dinornis and its allied genera. The former is small, but powerful, and very peculiar in its habits as well as its structure. It is truly wingless, having barely the rudimentary wing bones, and nothing that can in any way act as fore extremities. The Dinornis has already yielded nine species from the specimens exhumed, and of these one is believed to have been contemporaneous with the present races of animals and with man, even if living individuals are not still concealed on the island.

In Madagascar there have been found, not only bones, but the shells of such eggs as those gigantic birds may have laid, the contents of one egg of average size being six times that of an ostrich's, and a hundred and forty-eight times that of a hen's egg.

In the neighbouring island of Mauritius the dodo and the solitaire are examples of animals that have died out certainly within the last two centuries. They are, however, not only extinct, but forgotten, so that were it not for the bones and the actual painted representation of the bird, it might well be thought that they were animals of much more ancient date. All these birds of New Zealand and the islands of the Indian Ocean that are now extinct, were remarkable for the absence of any vestige of wings that could be available for flight.

The complete skeleton of the dodo has been found and its affinities are now determined beyond a doubt. Though a large bird, it had important relations with the pigeon tribe, and was, no doubt, good for food.

As the remains of birds are exceedingly rare in any but the newest deposits, and might have seemed to show that this important class was newly introduced, if it had not been for the solitary group of footprints in the red sandstones of Connecticut, so the yet more highly organised mammals—the highest group in the scale of beings—are known only in a fossil state in the secondary rocks by a few minute and imperfect fragments, not to compare in completeness with the envelope of the animalcule, the carapace of the crab, the shell of the mollusc, or the bony plates coated with enamel of some of the fishes.

It is singular that whilst, in the more highly-organised vertebrate animals, the proportion of hard to soft matter is generally larger than in those of lower structure, although the hard matter itself is at least equally indestructible, there should be this scarcity of their fossils. In quadrupeds generally, and in birds, the bones contain nearly seventy per cent. of hard earthy matter, chiefly phosphate of lime, while in reptiles the proportion does not average more than sixty per cent, and in fishes even less. The rest is chiefly gelatine, which, after long interment, is lost, and after a time is often replaced by a second dose of carbonate of lime, or by the infiltration of silica.

Professor Owen has observed that—"The determination of the remains of quadrupeds is beset (as Cuvier truly remarks) with more difficulties than that of other organic fossils. Shells are usually found entire, and with all the characters by which they may be compared with their envelopes in the museums, or with figures in the illustrated books of naturalists. Fishes frequently present their skeleton or their scaly covering more or less entire, from which may be gathered the general form of their body, and frequently both the generic and specific characters which are derived from such internal or external hard parts. But the entire skeleton of a fossil quadruped is rarely found, and when it occurs it gives little or no information as to the hair, the fur, or the colour of the species. Portions of the skeleton, with the bones dislocated or scattered pell-mell, detached bones and teeth, or their fragments merely—such are the conditions in which the petrified remains of the mammalian class most commonly present themselves in the strata in which they occur."*

The determination of all that is essential in the form, habits, and peculiarities of a quadruped, from a careful consideration of the analysis of single bones or teeth, or groups of bones, has for its basis an admission of perfect mutual adaptability of every part, combined with an obscure and mysterious reference to some general typical structure more or less developed in the particular instance, but very essential as marking the position of the species in question in the scale of nature.

Thus, in the whales and other marine cetaceans, there are rudimentary bones of no conceivable use to the individual, nor, indeed, to any one species of a large tribe, but which yet connect these animals with the class to which they belong, and separate them from other classes to which they approximate in form and habits, though not in some essential points of structure.

---

* Owen's "Palæontology," p. 297.

The earliest indication hitherto obtained of the existence of quadrupeds is from fossil teeth in the new red sandstone or triassic formations—among the oldest rocks of the secondary period, and the same as those in which the footmarks of gigantic birds were discovered. It is somewhat unreasonable to assume, as Professor Owen seems inclined to do, that because they have not yet been met with in palæozoic deposits, they had not then been created. Time will probably bring to light much that is new and interesting in this department of human knowledge.

The animal whose remains are above alluded to was a very small insect-feeding quadruped, possibly marsupial, and approaching one of the smaller Australian genera in its dentition. Other not very dissimilar remains, consisting of jaws and teeth, have been found in the rocks of the lower oolite worked at Stonesfield, near Oxford, and they also seem to indicate an animal whose teeth could conveniently crush the wing-cases of beetles and the hard integuments of other insects. Some of the animals whose remains are preserved were marsupial, and some not; but all seem to have been of small size. One of them was apparently omnivorous, and is suspected to have been hoofed. Others found in the beds of upper oolite were decidedly carnivorous, and others again herbivorous.

With the exception of a single bone, probably from an oolitic bed, and referred to a cetacean as large as a grampus, the above is the whole list of fossil quadrupeds from rocks below the tertiaries. Can we for a moment suppose that the earth was thus thinly and poorly provided with animals, while the air and water teemed with life? Can we believe that, with vast forests and a wide-spread and varying vegetation, with insects abundant, and every thing, so far as we know, perfectly favourable for their existence, there should have been a few, and yet so very few, mammalian forms developed; just enough to let us know that the class had long been introduced, but proving also, if this view be correct, that it had made, and was making, no advance towards its subsequent importance?

Doubtful, and contrary to experience as this might seem, it is a possible state of things, and one not altogether without example at present. Such was certainly the condition of some of the large islands of the Pacific when discovered, even so lately as during the last century, and such is still, perhaps, the state of islands almost as large as our own.

But if these islands are now exceptions to an otherwise general rule, that all the different classes are spread wherever circumstances are favourable for their growth, why should it not have been so formerly? Why should not islands with only a few small marsupial quadrupeds have existed in a great ocean in the western part of the northern hemisphere, while continents elsewhere were crowded with larger groups, and much larger individuals, of the class of mammals? Why, in other words, are we bound to assume that in our own latitudes there was always the same richness of life that there is now, and that here was the scale by which to measure all creation? Rather let us assume that land and water have not only always been unequally distributed, but that what are now the depths of ocean may once have been dry land, just as we know that what is now dry land was certainly for a long time, and when all these secondary deposits were going on, covered with water. From this water, no doubt, were deposited in the form of mud and sand, those very rocks from whose contents we now judge of the animal inhabitants of the whole globe. A due consideration of "the imperfection of the geologic record" would teach useful lessons of humility in reference to the introduction of the higher races on the earth.

By far the larger number of mammals whose remains have been found fossil belong to the period called tertiary, commencing after the deposit of the chalk.

Whether the chalk and the other rocks of that period in our latitude were deep sea deposits is by no means clear. Probably there was no great uniformity, but some parts were accumulated in deeper, and some in shallower water. But this cretaceous sea certainly covered an immense portion of what is now land, not only in Europe, but in large parts of Asia, Africa, and even America. The distribution of land and water after the completion of the secondary deposits, and at the commencement of what we call the tertiary period, must have been in all respects different; and it is only in the rocks of the latter that we find the mammalia fully represented.

The earliest form of modern quadrupedal life yet known was a large and remarkable animal, at least double the size of the American tapir, determined originally by Professor Owen from a single tooth and a small fragment of jaw dredged up off the Essex coast. Other teeth and bones were afterwards found, confirming the view originally taken of this animal, which differs from the later tapiroid animals, although, like them, it was herbivorous and hoofed. Another and somewhat peculiar hoofed quadruped was afterwards detected from the older tertiaries of the London clay, and these two seem to have preceded, in order of time, the well-known and often-described genera, the *Palæotherium* and *Anoplotherium* of Cuvier, the former representing a group of hornless rhinoceroses; the latter approaching the antelopes and deers in some of its species.

Since the original account given by Cuvier of the fossils from which these interesting and curious pachyderms were made out, a large number of new genera have been added, most of them nearly allied, and proving the singular abundance and variety, at the time when they lived, of a tribe now greatly limited in distribution.

Without reciting a long list of technical names, which could have no interest for the general reader, we may say that these discoveries have resulted in connecting together, by marked and very curious links, the common pachyderms, of which the elephant, rhinoceros, and hippopotamus, the hog and the horse are all examples (some of them very divergent); and not only have they shown the mutual relations of structure in these, but they have enabled the naturalist to understand how they all pass, by almost insensible gradations, into the ruminants—especially the antelopes. They are even considered to prove the artificial character of the order *Ruminantia* of modern systems of classification, and to show the natural character of that wider group of even-toed, hoofed animals suggested by Professor Owen many years ago, and for which he proposed the name *Artiodactyla.*

With the vegetable feeders of the old tertiary period, many of them small, delicate, and of beautiful proportions, there coexisted carnivorous quadrupeds which, to judge by their teeth, were more fell and deadly in their destructive task than modern wolves or tigers. One of these, about the size of a leopard, and others of smaller dimensions, seem to have been sufficiently abundant during the early and middle tertiary period. There were, also, then as before, a few didelphine animals, including an opossum from the classic beds of Montmartre. Besides these we have in the older tertiaries a very peculiar edentate, intermediate between the pangolins and orycterope; this latter in some of its proportions reminding the naturalist of the gigantic extinct sloths of South America.

A large carnivorous whale, several herbivorous cetaceans, several extinct dolphins and true whales, and a gigantic animal, probably a manatee, having large tusks in the lower jaw, are among the animals whose remains are also common in the middle tertiaries. Of these, the whales are known chiefly by a group of fossils, at first little suspected to be organic, in fact, by the petrified teeth and ear bones washed out of older beds into the red crag of Suffolk (a newer tertiary deposit), and there accumulated in such large quantities as to be of economic importance.

The vast number of these fossils, and the proportion of phosphate of lime in them, led the late Professor Henslow, in 1843, to call the attention of agricultural chemists to them, as a deposit of valuable mineral manure. Since that period they have yielded a large supply, worth many thousand pounds annually. The red crag is found in patches on the Essex and Suffolk coast, extending from the shore to from five to fifteen miles inland. It averages ten feet in thickness, but is in some places forty feet. Broken up septarian nodules form a rude flooring to the crag, left by the washing off of the London clay. The phosphatic fossils ('cops' as they are locally termed) occur on this flooring, and no doubt thousands of acres, many yards thick, of earlier strata must have been broken up to furnish the nodules now used to fertilise the land.

There is a distinct change in the grouping of the quadrupeds when we compare the older with the newer tertiaries, and some of the species form useful links. Thus, in later times the elephantoid group replaced the tapiroid, the mastodons being of intermediate character. Nearly, if not quite as bulky as the elephant, but not quite so tall, and with simpler dentition, these remarkable animals, with long straight tusks, and tusks in the lower as well as upper jaws, were probably more aquatic in their habits, and belonged to a more swampy condition of the land, in this respect resembling the hippopotamus.

The true elephants and some of the later mastodons, numerous hippopotamuses, rhinoceroses and hogs, many large ruminants of all the principal existing families, bears, porcupines and other rodents, and numerous vegetable and animal feeders, some of larger size than they are now found, others smaller but still different, and a few absolutely identical, characterise deposits of latest date, and mingled with such deposits have lately been found sculptured flints—certain indications of a race of intelligent beings, far removed from the lower animals, and proving, in fact, the very early introduction of man on the earth.

But long before this, the remarkable group now represented by apes, monkeys, and other four-handed animals, had been introduced, and their remains are found in the middle tertiaries of the south of France. One of these was apparently a tailed monkey, another was a large ape, long-armed, and of different build from the chimpanzee and the great ape of tropical Africa, and less like the human race in its osteological characters. Other monkeys and apes have been found in somewhat newer deposits, proving that these animals once ranged far more to the north than they now do. The last extinct species known was associated with the beds of gravel which contain bones of rhinoceros and hippopotamus, in which flint weapons are also met with.

We must not here occupy space by describing those very singular gigantic quadrupeds of the upper tertiaries, whose remains have for some years past attracted general attention, and have been the subject of frequent popular description. The megatherium and mylodon, the glyptodon, the sivatherium, the great Irish elk (so called) the great hyæna and bear of the caves, the huge kangaroo and wombat, and the powerful and fierce *Machairodus*, all these existed not long ago, and were associated in distant parts of the world, not only with man but with numerous quadrupeds still existing, and still the common and abundant animals of the countries in which they live. The horse and ass, and a third species of equus, intermediate in size, were probably the progenitors of those we employ. The same may be said of the bovine animals. In other cases, although certain large and obtrusive kinds are destroyed, the smaller kinds survived and still remain. In all these cases, "with extinct as with existing mammalia, particular forms were assigned to particular provinces, and the same forms were restricted to the same provinces at a former geological period, as they are at the present day," but this period in regard to the animals in question was a comparatively recent one.

We have now completed a very brief descriptive sketch of the great series of remains of animal life which form the basis of palæontological science, and though necessarily very imperfect, we believe such an outline may be found convenient and useful. Of course, in avoiding technical language and mere figures, we have left out much that would be essential in a treatise; but something of the order of nature will have been seen, and something of that foundation of fact, and superstructure of generalisation, that together construct the science.

Of all the direct and unmistakable deductions from these facts, the first unquestionably seems to be the apparent successive extinction of old species, and the substitution of new ones in their place. To the philosophical naturalist it thus becomes an inquiry; how far species are to be regarded as fixed and definite, and what, in fact, is to be understood by the term species, as expressing a fact in nature?

It is so difficult and unpleasant to unlearn what we have been taught as probably our first lesson in natural history, that scarcely any one is willing to give up this artificial and conventional term, and launch at once into the investigation that can alone enlighten us on this subject. Still, we are bound to inquire whether "species or forms, recognised by their distinctive characters and the power of propagating them," do exist in nature—that is, whether the limits of variety under changing external circumstances, are sufficiently known and considered,—when we assert that characters are distinctive, and whether the power of propagating distinctive characters is not combined with a large power of modifying the distinction in the offspring.

It is to this important question that Mr. Darwin some time ago directed attention, and in this he is decidedly at issue with the older naturalists. We have not space to give even an outline of the argument on either side, but our readers may be interested in observing the mode in which it affects the great palæontological inquiry.

Mr. Darwin, knowing that there are individual differences in all organic beings, capable of being repeated with more or less modification in offspring, believes that the conditions of existence, whatever they may be, determine the direction of change, by being always more favourable to some modifications than they can be to others. Under these circumstances, if the conditions, whatever they be, are used by one individual of a family to a greater extent than by the rest, that one will live and flourish while the others will starve or be killed; that one it is believed will also, in all probability, perpetuate its peculiarities, whatever they are, to some of its offspring, those of whom will be preserved who retain the favourable characters, while the rest will be lost, and so on until a permanent variety adapted to existing condition is produced.

But if the circumstances change, then some other corresponding modification of the organism is produced, and a new variety is obtained, and so on continually. There is no permanence in conditions, and therefore there is no necessary permanence in species; but conditions, and also species, may remain unaltered for a long period. There is correlation in a very important sense, and every change acts upon every individual. In this view the extinction of species is merely another mode of expressing that the mutual relations of inorganic matter, produced by those physical changes constantly going on, produce at the same time corresponding modifications in organic life. This we understand to be the meaning and bearing of the law of natural selection, and in this sense we understand and accept it.

In bringing this chapter to a close, we may make use of some remarks from a work recently published by Professor Owen, on Palæontology, and already quoted in previous pages. He observes that by the investigations of palæontology, we gain a knowledge of the fact that the phenomena of the world do not succeed each other with the mechanical sameness attributed to them in the cycles of the Epicurean philosophy, for we are able to demonstrate that the different epochs of the earth were attended with corresponding changes of organic structure, and that in all these instances of change, the organs still illustrating the unchanging fundamental types, were, as far as we could comprehend their use, exactly those best suited to the functions of the being. Hence, we not only show intelligence evoking means adapted to the end, but at successive times and periods producing a change of mechanism adapted to a change in external conditions.

CHAPTER XXI.

EFFECTS OF HUMAN AGENCY ON INANIMATE NATURE.

MAN has at all times and in all conditions of civilisation exercised an influence on nature far beyond that produced by any other race. Partly by direct means in his search after food, but chiefly, no doubt, indirectly and accidentally, as by the burning of prairies* and forests, and the removal of tribes of animals which in his absence would overrun the country, even savage tribes manage to make and leave a mark that cannot afterwards be effaced. But if this was the case in the early ages of the world and in all countries, and still continues in those wide tracts inhabited by men unacquainted with the luxuries of civilisation, it is enormously greater where civilised races have long dwelt, and much more so in the temperate than in the torrid or Arctic regions. It must not be supposed that this influence was always intended to be favourable, or that the result was foreseen. There can be no doubt that it has in some cases been altogether unexpected, and has even produced a great and permanent deterioration of climate, while in others it is possible that the climate may have been improved, large tracts being rendered habitable and healthy that were before useless. It is certain that the result might often have been foreseen where it was not; and the work has been done, whether for good or evil, long before the consequences were imagined.

---

* So effectual is fire, that on one occasion, in the United States, at Miramichi, nearly six thousand square miles of woodland were destroyed, and the heat consumed and burnt to a cinder the very soil itself. As an illustration, however, that accidents of this kind, when not due to man, leave little permanent mark, we may mention that in a quarter of a century the ground was again covered with trees of fair dimensions, except where cultivation and pasturage prevented their growth.—*Marsh*, "Man and Nature," p. 28.

There is not a doubt that the land in the temperate zones of the earth, as well as in the tropical regions, was originally covered with a dense forest wherever the conditions were favourable for vegetation; and in many places, as on the sides of almost inaccessible mountains, and on rocks now naked, where it would be least expected that forests could grow. This is proved by extensive vegetable remains—trunks, branches, roots, fruits, and even leaves of trees, frequently found in boggy tracts, on mountains, in plains and valleys, near the mouths of rivers, and in lakes. Such historical accounts as can be referred to prove that this was the case throughout northern and eastern Europe and north Africa, and also in North and South America.

It is impossible to travel through the countries on the northern shores of the eastern Mediterranean without recognising this fact. Where now there are absolutely naked limestone rocks, only covered with a scanty coating of herbs during the spring, we know there were once forests of large extent. In the island of Cephalonia parts of these forests remain. Where the forest exists there is a soil, but where it has been removed the soil has gone too. The rock soon becomes perfectly bare when its vegetable coating is removed.

The great persistency and energy with which vegetable life forces itself in wherever there is opportunity, and the mode in which the smaller tribes of plants pave the way for the larger, until such forest trees rise as the circumstances will allow, is a fact too well known to render it doubtful that in all cases there will exist trees, wherever trees can be induced or are allowed to grow. Certain animals, such as goats and deer, are especially injurious to young trees, and when introduced into a country in which they are not indigenous they soon check and destroy forest growth. Thus, in Cephalonia, to which we have just referred as an instance of a forest partly removed, we find that the presence of a few goats, which do no great harm to existing grown trees, entirely prevents the continuation of forest growth by destroying the young trees. Throughout the Ionian Islands and Greece, forests once covered the land. The forests have been destroyed, and the destruction dates from the encouragement of the goat at the expense of the pig. The destruction of wolves by human means must also tend to the increase of the browsing animals and the destruction of the forests. In this way, incidentally, the extirpation of certain tribes of animals affects the vegetable covering of the earth. It is exceedingly difficult to measure the extent of climatic change produced as the ultimate result of these forces; but that there is a very great effect, no one familiar with the facts of the case will attempt to deny.

In order to estimate the direct effect of human agency in civilised countries it is necessary to resort to figures. These will at any rate serve as the foundation for an estimate, however inadequate. Thus, it is calculated that in the year 1860 there were 160 millions of acres of land (250,000 square miles) under cultivation in North America, producing not less than 60 millions of tons of various kind of food, artificially grown for the use of man, and of those domesticated animals dependant on him. This vast quantity was grown by a population of 30 millions of human beings, introduced since the discovery of America. The whole of it may be regarded as the result of the introduction of civilised man, for a native population had doubtless been in existence since the time when the mastodon ranged over the prairies without in any degree affecting the balance of nature. It is not difficult to see that the diversion of so much land from a native state to cultivation, must have produced many important changes.

Man exerts influence in various ways. He destroys birds because they eat fruit. But these birds also feed upon the insects; and a worse evil is sometimes produced by the increase of insects than is corrected by the destruction of the birds. He destroys the wild animals and introduces tamed and domesticated kinds. But some of these are occasionally multiplied into nuisances. He extirpates worms, which might do him the greatest benefit if left alive. His influence, when conscious, is often in a wrong direction; and when unconscious may turn either favourably or unfavourably for his interests, according to circumstances over which he has no control. Even in the case of food recognised as valuable, such as the salmon and the oyster, he will often, with the most senseless and stupid carelessness, destroy the race for the sake of a few years supply.

As wooded lands are by no means adapted to human requirements, seldom furnishing either vegetable food by their fruits, or animal food by the fowls and beasts naturally resident in and about them, it is certain that the first result of any permanent settlement of men in a country must involve the destruction of woods. Even for fuel they would need to cut down a part; but for cultivation, they require to remove a large proportion of the forest growth of a newly-settled district. Fire is generally used to remove the surplus timber, as the result of burning is highly favourable to the production of a valuable soil for the growth of food crops. Forests have generally yielded very soon to the repeated attacks made on them as people multiplied and wants increased.

It has been supposed that trees exercise an electric influence on the atmosphere; and as the phenomena of vegetable life are numerous, energetic, and complicated, it is not unlikely that this is the case. It seems to be a universal opinion that hail has become more common and severe with the removal of wood on the flanks of the Alps, and in other places where forests have been destroyed within a short time. However this may be, the quantity of carbon absorbed, and the chemical change induced by the surface of leaves exposed in a forest, cannot fail to affect the atmosphere; and the removal of the forest alters the equilibrium obtained during successive centuries. A forest withdraws from the air, by its enormous absorbent surface, much more carbonic acid than meadows or cultivated fields, and exhales much more oxygen.

Whether regarded as mere inorganic matter or as a copious reservoir of life; whether as an absorbent, a radiator, or a conductor of heat, or even as merely covering the ground,—a forest has an influence on the temperature of the air and earth which demands careful consideration. If we represent the power of calcareous sand to retain heat by 100, we shall find that arable calcareous soil may be represented by 74·3, argillaceous earth by 68·4, garden earth by 64·8, and humus by 49. It follows that if a sandy soil be stripped of wood, the local temperature will be raised; while, if the soil consist largely of humus, the difference in this respect will be small. But there will always be a difference. It will be evident that the extent of surface exposed must in all cases be much greater when ground is covered with vegetation than when it is bare. Trees, however, act in many ways, not only as good conductors of heat but as helping to prevent radiation, both of heat and moisture, owing to the large surface of leaves they expose between the earth and sky.

In Italy, the clearing of the Apennines is believed to have greatly affected the climate of the valley of the Po, the result being that the sirocco now prevails greatly on the right bank of that river, in the territory of Parma, and in part of Lombardy, where formerly it is believed to have been unknown. The same is the case in Modena and Reggio. In these districts, in places where straw roofs once resisted the winds, tiles are now hardly sufficient. In others, where tiles were used, large slabs of stone are ineffectual, and in many neighbouring communes the grapes and grain are often swept off by the blasts of the south and south-west winds. On the other hand, it is recorded that when the noble pine forests near Ravenna, about twenty-two miles long, were cut down, the neighbourhood was found to suffer. The wood was afterward allowed to grow, and the city is now relieved from the sirocco and restored to its old climate. Another well-attested change of climate is recorded in Italy. When English iron was excluded from that country under the influence of Napoleon I., the furnaces of the valleys of Bergamo were stimulated to great activity. "The ordinary production of charcoal not sufficing to feed the furnaces and the forges, the woods were felled, the copses cut before their time, and the whole economy of the forest was deranged. At Piazza Torre there was such a devastation of the wood, and consequently such an increased severity of climate, that maize no longer ripened. An association, formed for the purpose, restored the forest, and maize flourished again in the fields of Piazza Torre."*

Similar results have been obtained in Belgium. By planting trees on the right bank of the Scheldt, where before there was no vegetation, an effectual shelter was soon formed, and the result has been to render fertile large tracts of land formerly waste. In France, there seems no doubt that the removal of the forests on the Vosges sensibly deteriorated the climate on the plains of Alsace, and the forests of the Cevennes, destroyed under the reign of Augustus, are said to have kept off the *mistral*, or north-west wind from the large and rich tracts near the mouth of the Rhone. Since then, the olive has retreated many leagues: the orange is confined to a few sheltered points on the coast, and fruit trees can hardly be reared in places where they were formerly easy of growth and very prolific.

---

* G. Rosa, in "Il Politecnico," December, 1864, p. 614.

Forests also check the movements of winds, and thus, in a sensible degree, diminish cold. In Canada, and the northern states of America, the engineers and firemen of locomotives employed on railways running through extensive forests, find it much easier to keep up steam while the train is passing through the woods. As soon as the train emerges from this shelter, it is necessary to supply fuel liberally, to bring up the heat.

It is very difficult to decide absolutely as to whether climate, in any part of the world, has really and permanently changed; but certainly the general testimony of experience and all historical accounts to which we can refer, point to this as a conclusion. Generally, throughout the north temperate zone, the summers seem to be cooler, moister, and shorter; the winters milder, drier, and longer than they were when forests covered the greater part of the land. The rivers, also, and streams have become more irregular; passing into torrents in summer, and drying up in winter.

With regard to the influence of forests on rain, it has been very distinctly shown in tropical countries, and cannot be doubted in the temperate climates of the northern hemisphere. In wooded and undrained countries, the atmosphere is generally humid, and rain and dew fertilise the soil, and the result is similar in its nature to that produced by the vicinity of a great ocean. The absence of wood is a great cause of the aridity of Spain. In France, many districts have suffered by clearing. Since the extensive clearings between the Spree and the Oder, the inhabitants complain that the clover crop is much less productive than before. On the other hand, examples of the beneficial influence of planting and restoring woods are not wanting. In Scotland, where many miles square have been planted, the effect has already been manifest, and in southern France similar observations have been made. In Lower Egypt, both at Cairo and Alexandria, rain formerly fell very seldom in considerable quantity. Thus, during the French occupation of Egypt, about 1798, it did not rain for sixteen months. Since, however, Mehemed Ali and Ibrahim Pacha completed their vast plantations, (the former, alone, having planted more than 20 millions of olive and fig-trees, cotton-wood, oranges, acacias, planes, &c.), there now falls a good deal of rain, especially along the coast, in the months of November, December and January, and even at Cairo it rains both more frequently and more abundantly—showers being no rarity.[*] Babinet, in his "Etudes et Lectures sur les Sciences d'Observation," testifies to the same fact in Egypt. Others have disputed the fact, but it seems that the general impression is that such is the result, although, no doubt, accurate observations, continued over a long term of years, would be required to determine the particulars satisfactorily.

Forests affect the supply of water to springs, for they protect the fallen rain from evaporation, and give it time to sink far into the interior. Many cases are recorded in America, upon the best authority, of streams flowing from woods, diminishing both in number and volume as the woods were removed. Mr. Marsh states, "I remember one case where a small mountain spring, which disappeared soon after the clearing of the ground where it rose, was recovered about ten or twelve years ago, by simply allowing the bushes and young trees to grow up on a rocky knoll, not more than half an acre in extent, immediately above it. It has since continued to flow uninterruptedly." Abundant and striking evidence as to this question is given by numerous observers. Thus, Vallés[*] and Boussingault[†] have quoted a number of cases; the latter writer pointing out, more especially, that even if the common opinion that the felling of woods diminishes the rain-fall is not true, there is at least a marked difference in the mode of its action on the earth's surface. He mentions, as resting on the best authority, the case of the valley of Aragua, in Venezuela, (South America). The valley is shut in, and several rivers entering it form a lake about the size of the lake of Neuchatel, at an elevation of 1,460 above the sea. The facts are curious and interesting.

At the time of Humboldt's visit to this valley, in the year 1800, there was a population as dense as in any of the best peopled parts of France, who had cleared the surrounding country of wood, and for thirty years the lake had been gradually lowering. Thus, in 1555, the town of New Valencia was formed on its banks, half a league from the lake; and at the time alluded to (1800), the distance had become about three miles and a third, the waters having receded nearly two miles. The intervening ground was covered with plantations, and many hillocks on this part retained the names of the islands of which they had previously formed part. There was, however, no outlet reaching the ocean. Twenty-two years after Humboldt's visit, M. Boussingault visited the valley, and found that the waters were gaining on the land. Islands, once cultivated, had become mere shoals. Cultivated grounds were submerged, and the inhabitants were dreading that they should be drowned. The political events that had intervened had caused an interruption of labour, and the forests had regained their strength. "At the time of the growing prosperity of the Valley of Aragua," says M. Boussingault, "the principal affluents of the lake were diverted to serve for irrigation, and the rivers were dry for more than six months of the year. At the period of my visit, their waters, no longer employed, flowed freely." The same author refers to several other very marked examples of the rapid lowering of the waters of lakes, where adjacent forests had been cleared away.

---

[*] "Asbjörnsen," as quoted by Marsh, p. 189.

[†] "Etudes sur les Inondations," p. 472.

[‡] "Economie Rurale." Chap. xx., sect. 4.

The inevitable result of the clearing away of forests over a large tract of country must be, that during one season the earth parts more rapidly than before with its heat, by radiation; at another, it receives an undue supply from direct exposure to the sun. The soil is alternately parched in summer and chilled in winter. The precipitation of rain becomes less regular. The surface becomes more and more exhausted of the elements of a good soil. The uplands become rapidly removed by degradation: the lowlands are injured by torrents covering the soil with rocky fragments; the channels of the rivers are choked, and their mouths interrupted by bars. A few exceptions to this, and the fact that in certain districts the climate does not seem to have been seriously deteriorated within the historic period, do not prevent the general conclusion here given from being correct.

It is certain that man, by removing forests in all those countries in which he is largely and successfully established, has done much to modify the climate, not only of his own but often of distant lands. And the result is not confined to what is seen, for the consequences extend far on into distant time, and produce modifications of which no one can trace the end. In the Alps, where the clearing has been pertinaciously carried on for centuries, the effects are very serious, not only the human population rapidly diminishing, but the whole face of the lower country being altered. In the Apennines, as we have seen, the case is the same. With regard to South America, the proof has just been laid before the reader. In Spain, it is certain that the climate is more excessive than formerly. There is no doubt that in every country where forests have been cleared, a similar result might in some degree be traced.

To understand the full amount of operations, such as have been narrated, it is necessary that the reader should bear in mind the transporting power of running water. This has been already considered, and instances of it have frequently been recorded. It is impossible to urge too strongly the importance of a due attention to figures in the determining the value of a force; and it is certain that the more accurately the facts are ascertained the more rapid, efficacious, and inevitable, will the existing causes of change on the earth be found, and the more clear will it be that in removing forests on a large scale man has done more to modify the earth than can be at all estimated, either now or at any future time.

The actual quantity of woodland required to secure for a country or a continent the best climate, cannot be determined without much careful consideration. In France, in 1750, the quantity of surface covered with woods was calculated at more than 40 millions of English acres. In 1860 this quantity was reduced to 20 millions. The total area of France is about 130 millions of acres. It is believed that if the distribution were well arranged the larger of these two areas would not be in excess, under the climatal conditions of France and the nature of its surface and soil. In other countries a different proportion of the area would be needed, and in the British Islands the vicinity of the sea and the nature of the prevalent winds render almost unnecessary those protecting influences which in the interior of a continent are so necessary.

But it is not only by the removal of forests that human agency is felt in nature. It is, no doubt, a result of the advance of civilisation, that man should, in his need of soil, of timber, and of fuel, destroy in few years the growth of centuries, convert by this means a district abounding with life, both vegetable and animal, into a sterile tract of naked rock, and injure permanently the plains at a distance of scores or even hundreds of miles. But he no sooner occupies a prominent place among the inhabitants of a district than he finds it necessary or convenient to act yet more directly in the way of coercing nature to lend herself to his schemes. By increasing the erosive action of running streams and the conveying power of water—the results of the clearing of mountain sides—he has often caused the extension of a coast line towards the sea, the filling up or the draining off of lakes, and the shifting of the beds of streams. He has also occasionally by artificial embankments limited and diverted the course of rivers, rescuing parts of the land near the sea from tidal overflow, and thus produced tracts of arable land, where before there was only a salt marsh. No doubt the quantity of soil thus gained in a term of years is small compared with the whole existing land, but it is not therefore unimportant. In this case, as in the case of forests, a very small positive and permanent alteration of any kind may, and even must, involve further change. One thing leads easily to another, and after years have elapsed, the result of insignificant changes may amount to a total worthy of notice among the larger phenomena of nature.

The draining of fens, and other low tracts of land near the mouths of rivers, or on a coast line, is one of the works by which man largely influences nature. In England the Lincolnshire and Cambridgeshire fens included nearly half a million of acres of marsh, pool, and tide-washed flat, all of which is now converted into arable land and pasturage. This work is identical in character with the reclamation of the fens on the opposite shores of the German Ocean, commenced probably more than a thousand years ago. They are certainly as old as this, even if the Romans did not, as has sometimes been supposed, construct sea dykes on the shores of Lincolnshire or Holland.

The total gain of land by dyking in the Low countries is estimated by the recent Dutch author, W. H. Staring, (*Voormaals en Thans*) at about nine hundred thousand English acres, or one-tenth the area of the kingdom. Most part of this is somewhat above low water level, but the whole is subject to inundation in case of an accident. Such accidents have occurred from time to time. Ring dykes are constructed on a gigantic scale, to form a first and outer bulwark against the sea. These, however, gradually sink in the soft mud, and when raised by fresh constructions, the increased weight only sinks them lower. It is said that in some places they have gradually sunk to the depth of from sixty to a hundred feet. Thus the expenditure of time and labour has been much greater than appearances would lead one to suppose. It must also be borne in mind that there has been an enormous loss, chiefly of poor lands without much soil, owing to the encroachments of the sea, and the neglect of certain dykes. There has also been a great loss by the removal of soil once gained.

The sea is constantly forming new banks at certain points of the coast favourable for the deposit of sand and earth, and the stratum of sand with shells thus obtained, serves as the foundation for dykes. The instant such banks are above the low-water level, reeds grow upon them, and much mud is entangled among the roots. In this way high-water level is reached, and then grasses grow, and the embankments are safe. These first embankments are constructed of sand and earth bound together by fascines and provided with sluices. The sluices are the most expensive part of the work, as they are constructed with piles, and are intended to be open at low water. The dykes slope outwards very gently, but the crown of the dyke is steeper. The height and thickness vary according to local circumstances of tide and wind, but they are generally from 15 to 20 feet above high-water mark. Many of the principal dykes are strengthened by piles driven deeply down into the bed of the sea. Thus, along the coast of Friesland, where no dunes exist, the dykes are on piles for a distance of 150 miles, and these piles are tied together by cross timbers and iron clamps, the interstices being filled with stones. One of the dykes (the Great Helder) is about 40 feet wide at the top, along which runs a good road. It slopes down 200 feet into the sea at an angle of 40°. At certain distances immense buttresses run out several hundred feet into the rolling sea. This gigantic artificial coast is entirely composed of Norway granite.

The soil thus preserved, though originally not above high water level, will, if not sinking or accidentally injured, gradually acquire height by the effect of continued vegetable growth; but there is often a shrinkage and settling of the earth that more than counterbalances this gain. In most cases it is necessary to make use of wind-power, working pumps which lift the water to a higher level and into a channel by which it can be conveyed to the sea. Steam engines are now very largely used for such purposes. In the drainage of the lake of Haarlem, recently effected, the principal engine was of 500 horse power, and drove eleven pumps, making six strokes per minute. Each pump raised eight cubic yards (1,320 gallons) to the stroke, making altogether 120 millions of gallons per diem. The lake was about fifteen miles in length by seven in greatest width, and covered an area of 45,000 miles. It had long been in a dangerous state, when, in December, 1836, it burst its barriers and overflowed 20,000 acres of land at the southern extremity of the lake. The mischief done was great, and it was felt that the time was come when the cause should be prevented. The work of enclosing the lake with a ring dyke was commenced in 1840, and lasted eight years, after which the draining occupied five years, when the lands were sold. The cost of the operation was £764,500, and the loss to the State may be estimated at about £100,000, a result thought favourable. There cannot be a doubt that the existence or otherwise of a large extent of low, flat land, near the mouth of a great river, cannot but have material influence on the adjacent coast. The force of the tidal wave, the direction in which it acts, the local currents, the configuration of the coast, the depth of water near shore, and the form of the bottom,—are all affected by changes produced on the coast by way of embankment.

Works have been carried on from time to time with the view of draining lakes, either for the recovery of lands till then permanently submerged, or for preventing accidents, by the sudden increase of volume of such lakes. Such works were undertaken on a large scale by the Romans, in Italy; and the surplus waters of the Lake Albano, about fourteen miles from Rome, whose present level is 900 feet above the sea, were drained in the fifth century by a tunnel, cut entirely with the chisel through hard rock, for more than a mile. This tunnel still answers its purpose. A much more considerable work was the drainage of the Lake Fucinus, about fifty miles east of Rome, exceedingly malarious, owing to its variable height and the accumulation of decaying organic matter on its bed. Julius Cæsar commenced this work, and it was partially completed by the Emperor Claudius, restored by Hadrian, and continued in use for some centuries. During the middle ages it was neglected, and has recently been completed once more by a tunnel of three and a half miles. The water will be prevented from rising above its lowest ordinary level, and it is believed that 40,000 acres of very fertile soil will thus be reclaimed. In Chili, a smaller but equally successful operation was executed in reference to the Lake Taguataga, and 8,000 acres reclaimed. In Switzerland, the Lake of Lungern was thus drained not along ago. The consequences of these operations often involve the breaking down of the former banks, and a rapid and complete change of the features of the surrounding land. They are also sometimes injurious, for, by the removal of small mountain lakes, which have served as reservoirs, the water-supply of districts below may be seriously interfered with.

The ordinary draining operations carried on now so extensively and systematically for the improvement of land, cannot but seriously affect the conditions of the soil for evaporation. The temperature of the earth in such districts must be raised and the distribution of the rain-fall affected. And as deep under-drains carry off the water imbibed by the soil from precipitation, and in other ways—much of which would naturally have moistened the rock to a great depth, and ultimately reached the sources of springs, coming out, perhaps, at a great distance—it cannot be that such operations, carried on over almost the whole of a great country, can fail to produce a permanent change in the distribution of the water, and thus upon climate. Accompanied by irrigation on a large scale the effect would, perhaps, be modified; but, practically, the larger operations of deep draining are rarely carried on where irrigation is needed.

Irrigation, however, itself requires some notice as a human agent. In the south and east of Europe, in Asia Minor, and in many parts of Asia, this method is uniformly and systematically adopted to insure an increased production. It is needed partly from the nature of the summer climate, which is continuously dry, partly from the porous nature of the soil, either composed of gravel or of porous and fractured limestone.

There can be no doubt that irrigation has been employed in the East from time immemorial. Solomon says, "I made me pools of water, to water therewith the wood that bringeth forth trees."—Eccles. ii. 6. Reservoirs are still to be found in all the ancient seats of human civilisation, and the fertility of Palestine may be said to have been dependant on the keeping up of these means of irrigation. In the south-east of

Spain, where there is irrigation, there are abundant crops; where water is absent or not used, there is a desert. In Turkey, also, the lands are flooded a number of times every season, to ensure a good crop, and an area of nearly 6,000 square miles of Egypt may be said to depend on the same means.

The result of this upon the water courses is very important. In Lombardy, ten thousand millions of gallons of water, a quantity equivalent to the entire volume of the river Seine in its average state, is said to be daily removed from the Po, to water an area of about 1,360,000 acres of land. The amount of water applied varies from 27 inches to as much as 300 inches of water, and is spread over the whole season. It will not surprise the reader after this to learn that in many parts of Spain where, under the Moors, irrigation was adopted, and where it is still largely carried out, almost the whole supply of very large rivers is absorbed, and the quantity they carry to the sea reduced to a stream so small that it can be waded across. In the geography of rivers, irrigation is capable of producing an enormous change, and in other respects it greatly affects the condition of the surface. In districts where crops are plentifully irrigated, the salubrity of the climate is often greatly interfered with, owing to the mixture of decaying organic matter with the damp air rising from the ground, and the climate is in other respects altered. In many parts of northern Africa there are appearances of efflorescence on districts now completely and hopelessly barren, which seem to be the result of former irrigation on a large scale, and these must be added to the results of this interference with nature effected by human agency.

Embankments are influential agents introduced by man, and serving to regulate (and thus greatly interfere with) the natural course of streams by preventing inundations, which often injure, though they sometimes improve the districts in which they occur. Reservoirs and pools keep back a portion of the flood waters of mountain streams, and reserve the water to be afterwards more slowly delivered. Much may in this way be done to prevent the great and terrible evils of inundations, and also to render available water that would otherwise run off uselessly to the sea. Artificial channels may conduct the waters, naturally flowing in one direction, into another stream or valley where the facilities of storage or of getting away the waters are greater. Such canals have often been resorted to with more or less success, in reference to this matter. In some cases they have been effected naturally. Thus, the river Ardèche at some distant period cut a channel for itself through a rock, deserting its former bed, which has long been filled up, though it is still traceable. In the floods of 1827, however, the tunnel thus formed was found insufficient, and the river regained its original course. It is known that many rivers have at various times deserted their channels, and not unfrequently new channels have been provided for the convenience of man, or for some special purpose.

The Val di Chiana, in Tuscany, affords a valuable instance of the result of human ingenuity, in diverting a stream from its natural course, reclaiming a considerable tract of land from barrenness to fertility, and improving the salubrity of the climate of a large district. This valley intervenes between the upper waters of the Arno and the Tiber, and the waters formerly flowed into the Tiber. In the Middle Ages, and down to the eighteenth century, the Val di Chiana was often devastated by the torrents pouring down from the Apennines, depositing great quantities of slime, and gradually converting the whole valley into an unhealthy and desolate marsh. The level of the valley was gradually rising, and a number of ponds and small lakes forming. In the seventeenth century, after consulting all the eminent engineers of the day, Torricelli suggested that, by controlling the flow of the torrents entering the valley, and causing them to deposit sediment at certain places only, the level of the area might be raised and modified in such a way as to cause the water to flow evenly and regularly down a single channel. For this purpose the river Arno was selected, and the water was made to enter as far down as possible. In this way and at small expense nature has been so regulated by man, even in these wilder and generally ungovernable movements, as to have secured for cultivation some 450 square miles of worse than useless land, converting it into valuable and healthful soil. The course of a stream has been in some measure reversed, and what was once mischievous and destructive, has been rendered safe and useful.

By various means, and occasionally to a very important extent, man has thus sometimes succeeded in checking the natural course of streams, preventing them from carrying away their banks and shifting their course. Even in the case of sands, which may be regarded as dry rivers, and which in some countries serve as barriers against the waves, but in others are themselves blown onwards by prevalent winds, it has been found impossible sometimes to check the advance. This is sometimes extremely important, as blown sands, in more than one instance on record, have destroyed cultivation and overwhelmed whole districts.

Large deposits of loose, fine sand occur in many parts of the world, under various geological and geographical conditions. In the great Sahara and other deserts, as well as on the shores of the German Ocean, the Bay of Biscay, and other coasts, these phenomena may be studied. Pure silica sands are always barren, and often very destructive. Originally produced by the action of the sea in rolling and rubbing stones and rocks to powder, they are sometimes troublesome when far removed from the sea. They may, however, often be checked while still in progress of formation on its shores. It has been calculated that the annual increment on the shores of Gascony is not less than 220 cubic feet of sand to the running foot of coast line. The total quantity thrown up in a year on this coast is estimated at nearly eight millions of cubic yards, or more than 12 millions of tons. All this is subject to the action of prevalent winds, by which the sand is moved, not always with the same rapidity, but steadily, unceasingly, and, it might be thought, uncontrollably.

This, however, is not the case. In the desert the palm is resorted to, not without partial success, to stay the advance of the dry torrent. But something more is needed where the winds are strong and blow from the sea, and where the sea itself is constantly providing a fresh supply of material; and it has been necessary to devise many contrivances to resist the advance, and fix the moving sand. In cases where this cannot be done, the formation of hills for the sake of shelter may be efficacious. The presence of such hills is sometimes not less important than their removal when circumstances are different.

So essential are engineering operations in this matter, that there is a whole literature on the subject in the Dutch language, and many valuable memoirs and books in German, Danish and French. To know how to modify, form, fix or dissipate advancing sand hills, it is necessary, first of all, to understand clearly their formation and the laws that usually govern them. G. P. Marsh, in his work on "Man and Nature," has thus briefly stated such laws.

It is well known that "under certain conditions sand is accumulated above high water mark on low sea and lake shores. So long as the sand is kept wet by the spray, or by capillary attraction, it is not disturbed by air currents; but as soon as the waves retire sufficiently to allow it to dry, it becomes the sport of the wind, and is driven up the gently sloping beach until it is arrested by stones, vegetables, or other obstructions, and thus an accumulation is formed which constitutes the foundation of a dune. However slight the elevation thus created, it serves to stop or retard the progress of the sand grains which are driven against its shoreward face, and to protect from the further influence of the wind the particles borne beyond it, or rolled over its crest, and fallen down behind it." The shore being uneven, the conditions of exposure different, and the winds variable, such banks are curved, broken, and unequal in elevation, and thus there result a number of irregularly pyramidal or conical hillocks connected at the base by low ridges with each other.

The elevation of such hills varies exceedingly. In southwestern France in sheltered places they attain a height of 300 feet, or more. On the western shores of Africa they are said to be 600 feet high, while on the exposed shores of Schleswig, Holstein, and Friesland, they range only from 20 to 100 feet.

Once formed, these hills should remain wet. They are held together partly by mere cohesion, partly by the infiltration of lime, clay, and iron, tending to form hard concretions here and there. The sands at the top are subject to be occasionally blown away, and they then form a second inner series or belt. Within, a tendency to stratification is generally evident, and they are especially liable to exhibit false stratification. There are also alternations of fine and coarser sand, with occasional belts of foreign material. Owing to the action of the wind they are formed into little waves, with ridges and furrows like those of water. The slope of the two sides is different. That towards the sea or prevalent wind, is not more than 5° or 10°, while on the sheltered side the angle is nearly 30°. Where the waves act at the foot of such hills, their seaward face will be undermined, and will form a vertical cliff. Inland dunes are less regular, the hillocks being less connected. They vary much, also, in different parts of the world.

The origin of dunes is very ancient, but it is doubtful whether in some cases their actual condition has not been the result of the clearing of forests within the country. It would seem that their natural tendency is to become fixed, and in that case clothed with vegetation. This is illustrated by the condition of the sand hills covered with pine forest at Arcachon and other places in the Landes, between the wine district of Medoc and the Pyrenees.

It is by taking advantage of this tendency that man is sometimes enabled to gain the mastery over nature, and shelter lands otherwise subject to destruction. When such lands exist, however, they must be regarded as in a condition of unstable equilibrium:—they need careful supervision and management, and neglect may produce great mischief. Thus, in 1825, owing to the neglect of the dunes on the coast of Jutland, a breach was made by the sea, converting the Lijmfjord (formerly a lake) into a sound, and the northern part of Jutland into an island. All the fish were suddenly destroyed, and even aquatic plants (*Zostera marina*) whose habitat is salt water, were killed by the sudden change. The neglect of certain precautions by human inhabitants thus involved a deposit of animal and vegetable organisms, and produced a distinct geological phenomenon, and that without any sensible change of the land surface.

The mode in which dunes are destroyed is either by the direct action of the waves or by the accidental formation of a cavity admitting the access of wind to the interior, by which the sands are first dried and then blown. The result of even a slight accident of this kind may be fatal to the existence of a whole line of dunes, and the originating cause is not unfrequently the work of the rabbits that burrow in them.

There are three ways in which human industry is applied to the sand hills; first, the actual creation of them where encroachments of the sea are threatened; secondly, the maintenance and protection of them when once formed, whether naturally or artificially; and thirdly, the removal of the inner rows when the main outwork is perfectly secure.

It is singular to observe how very small a protection will, under certain circumstances, become a useful foundation for a row of sand hills. A high cliff of itself prevents the accumulation of sand, but a wall, even if very low, will sometimes serve as the foundation of a wide belt of high dunes. Thus, in 1610, a sand dyke, three or more miles in length, and of no considerable height, thrown across a tide-washed flat between the Zuiderzee and the North Sea, occasioned the formation of rows of dunes a mile in breadth. A few years since the advance of the sea was checked very effectually in a similar way, and the Island of Ameland prevented from being quite intersected by the waves.

Dunes are sometimes protected by a facing of stone, or by piles, or by walls and buttresses running out from the foot of the dune to low water mark. These methods, especially the latter, are sometimes adopted on the chalk cliffs of England, and with much success. Burrowing animals should be carefully excluded, as they are the cause of great mischief, admitting the waves which soon undermine and break up a dune. There are, however, certain grasses, creeping plants and shrubs, that are admirably adapted by their habits of growth to bind together the shifting sands into a solid mass.

As many as 234 species of sand plants are known to botanists. Of all these the *arundo arenaria*, known locally by various names,—*marram* being that used in some parts of England, is by far the most important and valuable. It thrives only in loose sands, and in a saline atmosphere. It rises only to a height of twenty-four inches, but sends strong roots and rootlets to a distance of forty feet. Its roots thus bind together the dunes, and the leaves shelter the surface. When the sand ceases to drift the plant dies, but its decaying roots remain fertilising the soil, while the decomposing leaves assist in forming a layer of vegetable soil. It is soon followed by a succession of other plants, gradually advancing until forest trees can grow, or arable soil is obtained. The protection of dunes by planting has been largely adopted in France, where more than 100,000 acres of land, once shifting sand hills, have been completely reclaimed, and are now covered with forests, constituting the main wealth of the department in which they occur. The trees adapted to sand culture are chiefly pines, which afford a valuable supply of resin from year to year, besides the timber.

Very extensive plantations have been made on the shifting sands in Austria, between Vienna and the Sömmering Pass, in the great plains of northern Germany, and in some parts of Poland. On the other hand, the neglect of similar precautions has destroyed vast tracts, once extremely fertile in Arabia and Asia Minor. A direct result of the cultivation of sand dunes is the modification of climate, and the deposit of a larger quantity of moisture in the vicinity.

Besides the ways in which man has already modified the climate and natural features of the earth, by removing or planting forests, constructing embankments, making or emptying lakes, altering the course of streams, checking torrents and inundations, or keeping out the sea by making or fixing impassable barriers, as already alluded to in this chapter, there are others yet to be taken into account. By great engineering operations he has it in his power to cut across isthmuses and narrow necks of land, and bring into contact two waters before separated, perhaps existing at different temperatures, with different inhabitants, and even at different levels. It is impossible to exaggerate the importance of such works. The isthmus of Suez being intersected would bring the Mediterranean into the Red Sea, and convey the Persian Gulf waters into the Mediterranean. The cutting across of the isthmus of Darien would, for the first time in the modern history of the world, bring together the Atlantic and Pacific, and if a sufficiently large channel were afterwards cut by the water, might modify or alter the course of part of that great current of warm water on which the climate of western Europe depends. Either of these would open a vista of changes which could not be understood in all their bearings until centuries had elapsed. Much smaller, easier, and less costly works than these are capable of bringing about great results, and no one can say where the changes thus induced can stop. Even so very unimportant an accident as the falling of an iron bolt from a wreck to the bottom of the water, may leave a permanent mark on the world's history, for where such an event has happened on sands the sands have almost inevitably become cemented by the oxide of iron rapidly formed, and permanent solid concretions, perhaps of considerable size, may result. The existence of such concretions might determine other more important results. Not long ago a curious deposit of pebbles and sand, about a foot thick, was observed while forming the harbour of Elsinore. This deposit was due to the street-sweepings of the town, which had been deposited in some corner for many years, and had been distributed over the harbour by the waves. A landowner of Malta having a house and garden over a marine cavern thought to utilise the sea below by making a hole and pumping up the salt water for evaporation. The result was, that at high water the sea rushed through the hole thus made and threatened to destroy the house and injure the land adjacent. It would seem that it would only have been necessary to cover the hole, but once made it could not be stopped up, and the house became uninhabitable. Every one familiar with the sites of old cities in Italy and Greece must have noticed the incredible multitude of potsherds lying about. They form an actual geological formation. The same has been the case in recent times with regard to the heaps of ashes and rubbish at Cairo, which were so large that the removal of them by Ibrahim Pacha was looked on as one of the great works of the age. So, also, in all old cities the level of the ground is above the ancient level. The present pavement of Rome is twenty feet above the ancient road, and the present Appian way is nearly five feet above the former way. The towns of England built on the site of old Roman stations show the same rise, owing to the gradual accumulation of rubbish. Vast heaps of shells, accumulated during centuries by the ancient people who fed on the animals once within them, form rows of hills of considerable dimensions in some parts of western Europe.

There are other human operations that so far interfere with the ordinary operations of nature as to be worthy some notice before concluding this chapter.

Thus it has happened more than once in coal mining districts that whole seams of coal have been fired and destroyed. A coal mine in St. Etienne was fired in the fourteenth century, and continued burning for centuries. The result of such accidents must involve permanent alterations of several kinds in the rocks adjacent. Several instances of the kind are recorded. Beds of peat, also, have frequently taken fire, owing to mismanagement or carelessness.

In mines of other kinds, where large excavations have been made for the removal of metals and minerals, the result in course of time cannot but be important, for way is thus made for the passage of water and the subsequent deposit of other minerals. It is impossible to doubt that in this manner there is a foundation laid for modifications that will go on for centuries or even thousands of years.

The extensive removal of coal from the earth must also produce important results. In many coal fields whole strata of six, eight or ten feet of solid mineral, and sometimes much more, are taken out from a great depth. It cannot but follow that the surface rocks sink down to the same extent, but the sinking takes place very irregularly. Where the rocks are brittle they break, where they are tough they are squeezed into the interstices formed. Down to the level of the coal removed the whole of the rocks must be irregularly fractured, and remain much more subject to the infiltration of water from the surface than they formerly were. Deep springs, also, that would formerly have risen to or near the surface, may now be distributed long before they reach the surface. And this work goes on over hundreds of square miles of country, and the result must ultimately influence the whole of the coal countries.

It may seem difficult to imagine a limit to the effects produced, after a lapse of centuries, by all these human influences, for their effects are continually increasing within an ever widening circle. But, after all, they must be recognised as a part of the very constitution of nature, and they should not be regarded as interrupting or interfering with nature. There is ample provision for all such irregularities, and all of them together only represent those small perturbations in the orbits of the earth and planets, which are as much a part of the system as is the general harmony and permanence of the whole. Every part of the great method of creation is perfect, every apparent interruption and modification of the system is, in fact, only a part of the system, and the whole is governed, as it was designed, with a perfection of design and an even uniformity of action that leaves no room for interruption, interpolation, or novelty.

It is true that this view of the government of the universe does not accord with the feelings of those who desire to have their attention directed in a definite manner to the repeated and systematic personal intervention of a Divine Power, and who cannot recognise this Power without being able to trace what is called the finger or the hand of the Creator in all His works. In a certain sense no doubt every contrivance or, in other words, every arrangement in the universe may be made to yield evidence of this. But we would venture to suggest that the noblest view of creation, and a knowledge of the real greatness of the Creator, can only be learnt by those who seek to discover the much higher and nobler intelligence that designed the whole system. That there should be an interfering hand is a mark of weakness in the original plan. If the structure be perfect interference is not necessary.

All true science has for its object not only the observation of facts, but the investigation of methods and the discovery of laws. These laws can only be binding and unalterable because they cannot be changed with advantage—in other words, because they are perfect as being instituted by One who is himself perfect. The science of physical geography requires that we should discover the methods originally designed to secure the existence and permanent upholding of the system of our earth. It is true that we may never be able to do this thoroughly, but this, at any rate, should be the object in view. There is a real history to be learnt, and real deductions may be drawn from it. The object in these pages has been to narrate the facts and so much of the history as can be regarded as clearly established.

INDEX.

A.

Aar, river, 155.
Absorption of light, its meaning, 27; amount of, in passing through air, 225.
Absorption of heat, by a moist atmosphere, 26.
Abyssinian sources of Nile, 151.
Acalephæ, habits of, 364.
Aconagua, (Chili), 94, 307.
Activity of volcanoes, relative, 300.
Adansonia, (*baobab*) an African tree, 344.
Aden, volcanoes near, 304.
Adige river, 157.
Adler Pass (Alps), 75.
Ægean invertebrata, E. Forbes on, 356.
Affinity, its nature, 15.
Africa, its coast line, 65; a country of lofty mountains and elevated plains, 71; mountain systems, 87; plateaux, 106; low plains, 114; rivers, 158; lakes, 179; waterfalls, 185; reptiles, 370; birds, 373; quadrupeds, 377.
Ain, river, 156.
Air, 219; diathermic only when dry, 25; general properties of, 221; how kept in motion, 236.
Aix, Savoy, change of temperature of its mineral waters, 214.
Aix-la-Chapelle, gases in the springs there, 207; phosphates found there, 209.
Alabama river, 162.
Albano lake, 175; effect of draining, 432.
Albatross, habit of, 357.
Albert-Nyanza lake, 179.
Aletsch glacier, 197.
Alexandrian lake, 181.
Alleghany mountains, 95.
Alpine chain, 75, 76; glaciers, 197; the home of certain plants, 339.
Alps, slopes of, 71; snow line, 189.
Alsace, its climate affected by the removal of the forests of the Vosges, 425.
Altai mountains, 84.
Alteration of strata, 41.
Altered rocks, how produced, 7.
Altmühl river, 157.
Aluminium, 13.
Amazons, valley of, 102; connected with Orinoco by a natural canal, 152; river, 160; flora of, 343.
America, coast line, 65; a country of plains, 71; mountain systems, 89; plateaux, 107; low plains, 114; rivers, 159; lakes, 181; waterfalls, 186; west coast almost rainless, 262; how far a change of direction in the Gulf stream would affect its climate, 275; earthquake action in South, 322; earthquakes of North and central, 327; reptiles, 370; birds, 373; quadrupeds, 377.

Ammer-see, 175.
Ammonites, 394.
Amoor river, 164.
Amorphozoa, fossil, 388.
Anapa, flowing naphtha well at, 311.
Andaman islands, volcanic, 306.
Andes, slopes of, 71; general account of, 91; snow line, 189.
Angara river, 177.
Animal tissues bad conductors of heat, 22.
Animals, of plains, 120; peculiar habits of, foretel weather, 283; becoming extinct, 355.
Annelids, habit of, 361.
Annuals, nature of, 337.
Anoplotherium, 416.
Antarctic floras, their agreement with each other, 348.
Antigua, fossil wood, 209.
Antioch, loss of life in an earthquake at, 318.
Antioquia, knot of, 95.
Anti-solar points in the atmosphere, 234.
Antitaurus chain, 82.
Antirana (Andes), 95.
Apennines, 79; effect of removing forests in, 425.
Apteryx, its habitat, 374; its resemblance to Dinornis, 411.
Aqueous action, what it does in the earth, 52.
Aqueous vapour, results if removed, 26; in air, 222; a radiant, 246.
Arabia, mountains, 87; desert, 113; central plateau, 114; desert almost rainless, 262; tropical, its flora, 344.
Aracan mountains, 87.
Aragua, (Venezuela) effect of removing wood in, 427.
Aral sea, 177.
Aralo-Caspian plain, 110.
Araucaria, the trees of this genus characteristic, 345.
Arctic, lands, 62; highlands, 107; ocean, 127; current, 147; snow line of, 189; species of plants, range of, 340; vegetation, in Northern Asia, 350.
Ardéche, river, 156.
Areas, of land and water, 59; of European earthquake action, 326.
Arigina, (Japan) hot springs, 205.
Arkansas river, 161; springs near, 204.
Armenia, plains of, 104; birds of, 373; the home of some cultivated fruits, 350.
Arno river, 156.
Arsenic in mineral springs, 209.
Artesian springs, 202.
Articulata, fossil, 390.
Arundo arenaria, its value in fixing sands, 439.
Ascension Island, volcanoes, 305.
Asia, its coast line, 64; account of, 66; a country of lofty mountains, and high plains, 71; its mountains, 82; its plateaux, 104; its low plains, 112; its rivers, 163; its lakes, 177; volcanoes, 304; earthquake band of, 322; its tropical vegetation, 341; its Arctic vegetation, 350; its reptiles, 371; its birds, 373; its quadrupeds, 376.
Asteröids, 1.
Astrakhan steppes, 110.
Athabasca lake, 181.
Atlantic basin, sub-divisions, 129.
Atlantic ocean, 126; rivers draining into, 153; confervæ in, 352; mud made up of foraminifera, 389.
Atlas mountains, 88.
Atmosphere, its phenomena can only be understood by a study of physics, 29; in its ordinary state not diathermic, 25; general account of, 221.
Aurora borealis and australis, 31; considered as a weather indicator, 286.
Australia, its coast line, 65; its land, 66; a land of unwatered plains, 71; mountains, 96; plateaux, 106; plains, 118; rivers, 165; lakes, 181; prevalent winds, 241; effect of west winds on east coast, 274; earthquake band of, 323; vegetation, 344; birds, 374; quadrupeds, 377.

Auvergne, arsenic in its mineral springs, 209; extinct volcanoes of, 314.
Avalanches, 192.
Average slopes of mountains, 60.
Axis, shifting of the earth's, 8; principal direction of lands, 63.
Axis of crystals, ready transmission of heat through, 22.
Azores, new island, 317.

B.

BACULITE, 394.
Bagnéres de Luchon, sulphur in baths at, 208.
Baikal lake, 177.
Baku, bitumen at, 210.
Bala lake, 173.
Balkan, a continuation of the Alps, 76.
Balkash, lake, 177.
Baltic, plain, 110; sea, 126; its tributaries, 153.
Bananas, home of, 339.
Band of intense earthquake disturbance, 321.
Bands of clouds, 252.
Baobab, an African tree, 344.
Barégees, increase of temperature of springs at, 215.
Barégine, account of, 213.
Barken lake, 176.
Barometer, account of, 284; daily oscillations of, 223.
Basalt, ancient lava, 37.
Basins, oceanic, 128.
Bath, hot springs of, 205.
Batrachian fossils, 405.
Bay, of Biscay, its waves, 141; of Fundy, high tide in, 143.
Belemnite, 395.
Belgium, earthquakes of, 327; effect of planting in, 425.
Beloochistan almost rainless, 262.
Ben Cruachan, (Scotland) 81.
Ben Nevis, (Scotland) 81.
Bergamo, the iron-making there affected the climate, 425.
Bex, salt springs of, 218.
Bienne lake, 174.
Birds, flight foretels weather, 283; belonging to the sea, 357; distribution of, 372; fossil, 410; effects of destroying, 423.
Bismuth, its irregular expansion, 21.
Bitumen with hot springs, 210.
Bivalve fossil shells, 392.
Blackdown fossil sponges, 388.
Black hills, Mexico, 91.
Black Sea, 126; its colour, 139; mud volcanoes on shores of, 310.
Black Stream of Japan, 147.
Blackwater river, 155.
Blue colour of the sky, 230.
Blue grotto at Capri, 138.
Blue Nile, 158.
Bodmin, rain-fall at, 260.
Bohemia, tin oxide in mineral waters of, 113; Lisbon earthquake affected springs of, 329.
Böhmerwald, mountains, 81.
Boiling point of water at various elevations, 225.
Boiling springs, 205.
Bolivian Andes, 94.
Bolsena lake, 175.
Bombon, plain of, 94.
Bon-Chater, arsenic in springs at, 209.
Boracic acid in Tuscany, 209.
Bore, the wave so called, 143.
Borrowdale, glacial action in, 198.
Botanical regions, 338; of the British islands, 348.
Boulou springs, cobalt and nickel found there, 213.
Bourbon l'Archambault, springs of, 204.
Brachiopoda, 391.
Brahmapootra river, 163.
Brasil, lakes, 183; flora, 343.
Brazil current, 146.
Brazilian coast, monsoons of, 240.
Brienz lake, 174.
Bristol hot springs, 205.
Bristol Channel, high tide in, 143.
British islands, 70; mountains, 81; plains, 102; rivers, 155; rain-fall, 260; climate, 271; earthquakes, 321;, botanical districts of, 348.

Bryozoa, fossil, 390.
Building material, granite as, 35.
Butterflies, wide range of, 367.
Bygle Fjeld, (Scandinavia), 80.

C.

Cæsium, a new metal discovered in mineral waters, 206.
Cairo, rain there more frequent since the planting of trees, 427; rubbish heaps at, 441.
Caithness flags contain organic remains, 401.
Calabria, account of, lives lost during earthquakes at, 318; great earthquakes of, 329.
Calamite, 387.
Calcareous soil, its heat-retaining power, 424.
California, mountains of, 90; great basin of, 107; some of its springs yield potash, 211.
Canals, natural, 434; artificial, 435.
Cambrian rocks, fossils of, 44, 386.
Cambridgeshire, effects of the fen drainage on climate, 430.
Cape of Good Hope, table land, 106.
Cape de Verd, volcanoes, 305.
Caraccas, earthquake, 317; noises during an earthquake there, 319.
Carbon in mineral water, 209.
Carbonate of lime, its abundance in rocks of certain ages, 47; found in water, 207.
Carbonate of soda abundant in Vichy water, 211.
Carbonic acid common in water, 209.
Carboniferous system, 45.
Caribbean sea, 127.
Carlsbad springs, 204; contents of, 211; incrustations in waters of, 212; iron at, 213.
Carnic Alps, 76.
Caroline Archipelago, 69.
Carnivora, how distributed, 375.
Carpathian mountains, 78; plateau, 103.
Casiquiare (natural canal), 160.
Caspian sea, deposits in, 171; general account of, 177; mud volcanoes near, 310.
Catskill mountains, 95.
"Cats' tails," clouds so-called foretel weather, 281.
Caucasian chain, 82; volcanoes, 304.
Caucasus, Indian, 83.
Cauterets springs of, 204; temperature of water increased, 214.
Cayambe (Andes), 95.
Celebes, its quadrupeds, 377.
Celestial mountains (China), volcanoes of, 306.
Central America, plains of, 107; earthquakes of, 322, 327.
Central Europe, its flora, 349.
Central France, hot springs of, 205; volcanoes of, 314.
Centres of creation, new, 353.
Centre of disturbance of an earthquake not easy to discover, 320.
Centre, specific, 381.
Cephalaspis, fossil fish so-called, 400.
Cephalonia, effect of removing forest in, 422.
Cephalopoda, fossil, 394.
Cevennes range, 81; effect of removal of the forests of, 425.
Chagos Archipelago, 70.
Chalk, 47.
Champlain, lake, 182.
Change in earth's excentricity, 4.
Change of rocks after being deposited, 49.
Change of specific form in organic beings, 335.
Changes, possible, in the distribution of land, 61.
Charybdis, 148.
Chaudes Aigues springs, 205.
Cheirotherium, 405.
Cheltenham springs, contents, 211.
Chemical action, a form of force, 19; a form of motion, 27.
Chemical affinity produced by electricity, 27.
Chemical change, how consistent with apparent tranquillity of the earth, 51.
Chiem-see, 175.

Chili, Andes of, 93; volcanoes of, 307; earthquakes of, 327, 330; drainage of lake in, 433.
Chilling effect of radiation, 247.
Chilōe earthquakes at, 330.
Chimborazo (Andes), 95.
China, snow in, 189; mud volcanoes, 311.
China sea, 127.
Chincha islands, guano of, 358.
Chlorine, 13.
Churchill river, 166.
Circulation of water, 149; of the atmosphere, 237.
Cirrostratus clouds, 252.
Cirrus clouds, 252; foretel weather, 281.
Civil year, exact length of, 5.
Clay slate, 39.
Cleavage of slate, 39.
Cliffs, remarkable, 65.
Climate, affected by excentricity of earth's orbit, 4; account of, 265; change of, probable in recent times, 426.
Clouds, their phenomena, 248; their effect on climate, 272; foretel weather, 281.
Club-mosses, of Java, 342; found fossil, 386.
Clyde, river, 155.
Coal, deposits of, 386; effects of removing, 441.
Coanza river, 159.
Coast line, an important phenomenon, 62.
Coast lines of Europe and Asia, 64; of Africa, the two Americas, and Australia, 65.
Cobalt, found in water of, at Boulou springs, 213.
Coocosteus, fossil fish so-called, 400.
Cochabamba, Sierra of, 94.
Cockles, distribution of, 393.
Cod, its great productiveness, 360.
Coese, nitrogen in water at, 208.
Cohesion, 18.
Col du Geant (Alps), 75.
Cold diminished by presence of forests, 426.
Colorado river (Upper California), 165.
Colour of sea water, 138; of the atmosphere, 230; of meteors, 244; of cirrus clouds, 252; of clouds at certain times, 256.
Columbia river, 165.
Combinations of common elements, how obtained, 11, 15.
Comets, 2.
Como, lake, 174.
Compass, variation of, 30.
Composition of atmosphere, 221.
Compression of the earth, 3.
Comrie (Scotland) earthquakes observed at, 329.
Conditions favourable for vegetable life, 338.
Conduction of heat, 22.
Confervæ in sea water, 352.
Coniferæ, fossil remains of, 386.
Coniston, rain-fall at, 260.
Connecticut river, 162.
Constance, lake, 174.
Contact, as influencing the action of forces, 18.
Content, solid, of the earth, 3.
Continents defined, 58.
Conversion of forces into one another, 28.
Conversion of mist into cloud, 258.
Copiapo, earthquakes at, 330.
Copper, in mineral springs, 213.
Coprolites, 397.
Coral animal, its distribution, 364.
Coral islands, 68.
Corals, fossil, 390.
Cordillera of the Andes, 91.
Coseguina, volcano of, 297.
Cotopaxi (Andes), 95; volcano of, 297, 307; noises heard during an eruption of, 319.
Cotteswold hills, 99.
Crater, volcanic, 294.
Crimea, mountains of, 81; mud volcanoes of, 310.
Crocodiles, distribution of, 370; fossil, 409.
Crowding out and starvation of individuals and species a law of nature, 384.

Crustaceans, habit of, 360.
Crystals, conveyance of heat along the axis more rapid in some cases than in any other direction, 22.
Cryptogamia, 336.
Cuenca mountains, 81.
Cultivation of land in North America, 423.
Cumberland, lakes of, 172; glacial action in, 198.
Cumulo-stratus clouds, 253.
Cumulus clouds, 252.
Curran Tuhol (Ireland), 81.
Currents, marine, 144.
Cuttle fish, habits of, 361.
Cuzco, knot of, 94.
Cycads, common fossils, 386.
Cycloid fishes, 402.
Cyclonic storms, 244.
Cyrus river, 166.

D.

Daily oscillations of the barometer, 223.
Dalbo lake, 176.
Dalmatian mountains, 78.
Danube, valley, 101; river, 157; rapids of, 185.
Dark lines in the spectrum, how caused, 27; appearance of, when seen in the upper part of the atmosphere, 234.
Darling river, 165.
Dartmoor rain-fall, 260.
Darwin, Mr., on the origin of species, 384, 395.
Dead sea, deposits in, 171; account of, 179.
Deccan, 87; plateau, 106.
Deciduous trees, home of, 339.
Deep soundings, 130.
Deer lake, 181.
Definite order not traceable in stratified rocks, 41.
Deflection of the needle, 31.
Delaware river, 162.
Deltas, 149.
Density of rocks, 7.
Deotsuh, plateau of, 105.
Depth, distribution of marine animals in, 355.
Depths of the ocean, 60.
Derwentwater lake, 173.
Desaguadero, plateau of (South America), 94, 108.
Deserts, their floras, 350.
Development of complex plants, 337.
Dew, phenomena of, 246.
Diamagnetic metals, 30.
Diathermic, meaning of the term, 25.
Dicotyledons, 337.
Dicynodon, a South African fossil reptile, 407.
Diminution of temperature in the upper part of the air, 225.
Dinaric Alps, 78.
Dinornis, 411.
Dispersion of light, 226.
Distance of the moon from the earth, 4.
Distribution of land, 58; of volcanoes, 298; of earthquakes in time, 323; of plants, 333; of animals, 354; of life in time, 378.
Disturbances, magnetic, 31; of strata, 41.
Divisions of the earth, how produced, 16.
Dneiper river, 157.
Dniester river, 157.
Dodo, a recently extinct bird, 412.
Don river, 157.
Dordogne river, 156.
Double refraction of light, 233.
Douro river, 156.
Dovre Fjeld (Scandinavia), 80.
Drainage areas, 167.
Drainage, its influence on climate, 430.
Drave river, 157.
Dredge for deep soundings, 130.
Drôme river, 156.
Dry air, diathermic, 25.
Dublin rain-fall, 260.
Dugong, distribution of, 357.
Dunes, their value in checking the advance of drifting sand, 437.
Durance river, 156.

Dwina river, 165.
Dykes, effect of on climate, 430; example of gigantic, 431.

E.

Earth—its revolution, position, magnitude, compression and surface, 3; its distance from the sun, 4; how regarded in a treatise on physical geography, 16.
Earth's crust, how made up, 6; its estimated thickness, 8.
Earthquakes, connection with volcanoes, 316; various kinds, 318; destruction to human life by, 318; alarm felt during, 319; accompanying phenomena, 319; distribution in space, 320, 323; general conclusions on this subject, 323; distribution in time, 323; seasons of most earthquakes, 326; relation to moon's age, 328; small shocks, 328; example of violent earthquakes, 329; distance of point of origin, 330.
Easter island, volcanic, 307.
Ebro river, 156.
Eddies, 147.
Edinburgh rain-fall, 260.
Eger river, 154.
Eggs of gigantic birds found fossil, 412.
Egypt, silicified wood of, 209; result of planting in, 426.
Eifel springs, rich in iron, 213.
Elbe river, 154.
Elburz (Caucasus), account of, 82; volcanic, 304.
Elective affinity, 15.
Electric current, resulting from two metals in contact, 23.
Electric storms, account of, 242; influence climate, 273.
Electrical action, during change of mist into cloud, 258.
Electricity, action of, 19; conduction of, 22; varieties of, 23; produces magnetism, 27; excited by mere heat, 27.
Elements, their nature, 9.
Elephants, 417.
Elevation, of strata, 41; of land, paralleled by depressions of sea, 60.
Elsinore, curious deposit at, 440.
Embankment and recovery of soil, its effect on climate, 430.
Embankments, their value in preventing inundation, 434.
Enare lake, 176.
Engineering works as influencing natural features, 440.
England—mountains, 81; plains, 102; rivers, 155; lakes, 172; snow falling in, 190; rain-fall, 260; climate, 271; earthquakes, 321; comparison of its flora with others in Europe, 348.
Entomostraca, fossil, 390.
Equatorial mountain range in Africa, 89.
Equilibrium of solar system complete, 6.
Equinoxes, 5.
Erie lake, 182.
Eruption of a mud volcano, 309.
Erzgebirge (mountains), 81.
Essential oils, their vapours render air opaque to heat rays, 25.
Estrella mountains, 81.
Ether, extension of, 2; agency of, in producing light and heat, 24.
Etna, account of, 301.
Eucalyptus, characteristic of Australian floras, 344.
Euphorbia, characteristic of African flora, 343.
Euphrates river, 163.
Europe—coast line, 64; land, 66; hilly and mountainous, 71; mountains, 75; plateaux, 103; low plains, 110; rivers, 153; lakes, 173; waterfalls, 185; climate, 274; climate affected by Gulf stream, 275; volcanoes, 300; areas of earthquake action, 326.
Evans, Mr., on shifting of the earth's axis, 8.
Evergreen trees, home of, 339; characteristic of southern Europe, 349.

Excentricity of earth's orbit, 4.
Expansion of water in freezing, 191; of air when heated, 224.
Expansion by heat not universal, 21.
Explosion, volcanic, 318.
Extinct volcanoes, 314.
Extinction of species, 355, 419.

F.

Facies of vegetation—its meaning, 343.
Falkland islands, no reptiles in, 372.
Faro islands, plateau of, 106.
Fata Morgana, 228.
Faunas, marine, compared, 383.
Fens, drainage of—effect on climate, 430.
Ferns, account of, 336; the commonest fossil plants, 386.
Fichtelgebirge (mountains), 81.
Fjords, most remarkable, 65.
Firn, 193.
Fishes, habits of, 358; remains found fossil, 396.
Fissures in granite—their contents, 35.
Fitzroy, Admiral, quoted, 245.
Fixed stars contain some of same elements as the earth, 9.
Floating of clouds, 256.
Floor of Atlantic ocean, 131.
Floras, distinct, how produced, 340; special, 341; Indo-Malayan, 341; Javan, 342; Hindostan, 342; tropical South American, 343; tropical African, 343; Arabian, 344; Australian and New Zealand, 345; North American, 345; islands in the Pacific, 347; temperate regions of the Old World in Europe, 348; China and northern Asia, 350; marine, 351.
Fluate of lime, found in mineral waters at Vichy, 212.
Fluidity, how produced, 21.
Fluorine, 13; found in mineral springs, 209.
Fog, how produced, 248.
Fog bank, 255.
Footsteps of birds, 410.
Foraminifers, their habits, 365; fossil, 388.
Forbes, Professor E., on the distribution of marine animals, 355.
Force, physical, 18; never lost, 20, 28; resolvable into life, 28; expended in formation and evaporation of rain, 262.
Forces of nature, interchangeable, 28.
Forchammer, Dr., on the contents of sea water, 133.
Forest vegetation of South America, 345.
Forests, result of destroying, 421; their effect on the atmosphere, 424.
Form of earth, irregular, 3.
Forms of force, identical, 28.
Forms of matter on the earth, 9.
Formosa, a volcanic island, 307.
Fossil footsteps, 403.
Fossils, account of, 379.
France—mountains, 81; plateaux, 103; rivers, 155; lakes, 173; mineral springs, 204; extinct volcanoes, 314; earthquakes, 327; forest land in, 429.
Franconian Switzerland, 100.
Fraser river, 164.
Friction, action of, in producing heat, 20.
Friesland, coast of, effect of dykes there, 431.
Frigate bird, habit of, 357.
Fucinus lake, effect of draining, 432.
Fulda river, 154.
Fundamental rocks, 33.
Fungi, growth of, 336.

G.

Galapagos islands, volcanic, 307; flora of, 347.
Gambia river, 159.
Ganges, valley, 101; river, 163.
Ganoid fishes, 401.
Gaps in geological succession, 44.
Gard river, 156.

Gariep river, 159.
Garonne river, 156.
Gases—their influence in destroying the diathermism of dry air, 25; they absorb the same rays that they emit, 27; those found in sea water, 135.
Gascony, moving sands on coast of, 436.
Gazost, organic matter emitted thence, 214.
Geneva, lake, 173.
Geographical position, an element of climate, 270.
Geologic record, imperfection of, 396.
Geology, a part of physical geography, 16; account of, 32.
Germanic plains, 110.
Germany, north, its crops deteriorated by clearing the forests, 426.
Geysers, noticed, 306; silica deposited near, 209.
Ghâts of India, account of, 87; rainfall, 239.
Girgenti, mud volcanoes near, 311, 363.
Gironde river, 156.
Glacial period, how caused, 5.
Glacial action on rock, 200.
Glaciers, of Alps, 76; of Pyrenees, 78; of Himalayans, 84, 197; of New Zealand, 96, 197; general phenomena of, 193; of Greenland, 197.
Glairine, found at Bex, 213.
Glass not diathermic, 25.
Glockner, Grosse (Tyrol), 76.
Gneiss, 38.
Goats, the destruction they cause to young trees, 422.
Gobi, plains of, 86; desert of, 105; almost rainless, 262.
Godavery river, 163.
Godwen-Austen, Capt., on Himalayan glaciers, 197.
Government of the universe, general remarks on, 442.
Graham island, 303.
Gran river, 157.
Granite, not always ancient, or formed at great depth, 7; account of, 33; has not been fused, 36; a metamorphic rock, 51.
Graptolites, fossils sò-called, 389.
Gravel, deposit of, 47.
Gravitation, 18.
Great Basin of California, 107.
Great Bear lake, 181.
Great Fish river, 163.
Great Glockner (Tyrol), 76.
Great Slave lake, 181.
Greek Archipelago, earthquake band through, 322; volcanoes of, 364.
Greenland, glaciers of, 197.
Greenstone, a water-formed rock, 51
Grotesque clouds, 253.
Ground swell, 141.
Grouping, of rocks, 45; of land, 62.
Guadalquivir river, 156.
Guadarama mountains, 81.
Guadiana river, 156.
Guano of Iquique, 358.
Guatemala, table land of, 107; volcanoes, 308.
Guioma mountain (Pindus), 78.
Gulf of Mexico, 127.
Gulf stream, account of, 145; effect of change in its direction on climates, 275.
Gum tree, characteristic of Australian floras, 344.

H.

Haarlem, drainage of lake of, 432.
Haast, Dr., on New Zealand glaciers, 197.
Hail, its formation, 190; becomes more common when forests are removed, 424.
Halos, how produced, 231; where formed, 252.
Hamite, 394.
Handek falls, 184.
Hanhai desert, 105.
Hardy plants range widely, 341.
Hartz mountains, 81.
Hawaii, volcanoes of, 295.
Heat, influence of, on combinations,

10; a form of force, 19, 21; how produced, 19; conduction of, 22; travels best along the axis of crystals, 22; developed by electricity, 22; excites electricity, 27; its influence on chemical action, 27; an essential part of climate, 265.
Heat rays, their position in the spectrum, 23.
Hecla, account of, 305.
Heated wire conducts electricity more slowly than when cool, 23.
Height, ordinary, of clouds, 249.
Helstone rain-fall, 260.
Henslow, Prof., on phosphatic fossils, 417.
Herring, its distribution, 359.
Heteropoda, fossil, 394.
Hielmar lake, 176.
High peaks of the Alps, 75.
Hills, definition of, 97; sandy, in France and Africa, 437.
Himalaya, slopes of, 71; mountain chain, 83; snow line, 189; glaciers, 197; limits of trees on, 339; certain flowers obtained from, 350.
Hindustan, mountains of, 87; flora of, 342.
Hindu-Koosh, 83.
Hippurite limestone, 393.
Hoang-ho river, 164.
Home, natural, of plants, 339.
Hooker, Dr., on fossil foraminifera, 389.
Hopkins, Mr. W., on rigidity of rocks, 8.
Horizontal space, distribution of plants in, 336.
Horse, a native of western Asia, 354.
Horse latitudes, 239.
Hot springs, 205.
Huanuco, knot of, 94.
Hudson river, 162.
Human influence, on climate, 277; on inanimate nature, 421.
Human interest of plains, 121.
Humboldt, his theory of volcanoes, 313.
Humboldt's current, 147.
Humidity, characteristic of certain climates, 347.
Humus, its heat-retaining power, 425.
Humming birds, characteristic of America, 374.
Huron, lake, 182.
Hydro-carbons, found in mineral springs, 210.
Hydrochloric acid, in mineral springs, 208.
Hydrogen gas, 12.

I.

IBERIAN plateau, 103, 104.
Ice, not diathermic, 25; phenomena of, 188.
Icebergs, nature of, 194; in the Atlantic, 199.
Iceland, springs, 205; volcanoes, 305; earthquakes, 326.
Ichnology, 403.
Ichthyosaurus, 406.
Identification of strata by fossils, 43.
Ille, river (Germany), 155.
Ilmen, lake, 176.
Impact, heat the result of, 20.
Imperfection of the geologic record, 396.
Impressions of animals, &c., how preserved, 404.
Indestructibility of force, 28.
India, mountains of, 87; northern earthquake band of, 322.
India-rubber, its irregular expansion, 22.
Indian Archipelago, 69; birds of, 373.
Indian Caucasus, 83.
Indian Ocean, islands of, 70; account of, 127.
Indighirka river, 166.
Indo-Australian archipelago, 341.
Indo-Malayan flora, 341.
Indus river, 163.
Inequalities of earth's surface, 16.
Influence of man on inanimate nature, 421.

Inlets, position of remarkable, 65.
Inn, river, 157.
Inosculating rivers, 152, 160.
Insects, foretel weather, 283; distribution of, 366.
Interior of the earth, 6; its density, 8.
Intermittent springs, 215.
Introduction of new forms of life, 397.
Inundation prevented by embankment, 434.
Ionian islands, result of removing forest in, 422.
Iquique, guano on, 358.
Irawaddy river, 164.
Irak plains, 105.
Ireland, mountains of, 81; plateau of, 106; lakes, 173; rain-fall in, 260; its flora compared with that of Spain, 348.
Iron, 13; polarity of, 29; in spring water, 213.
Iron ores in limestone, 50.
Irregularity of motions of earth and planets, 6.
Irrigation as a human agent, 433.
Irtish, river, 165.
Isar, river, 157.
Ischia, an extinct volcanic district, 363.
Isere, river, 156.
Isker, river, 157.
Island, new, in the sea, near the Azores, 317.
Islands, groups of, 58; their nature, 68.
Isothermal lines, 266.
Isthmus of Suez or Darien, result of cutting across, 440.
Italy, rivers, 156; lakes, 174; volcanoes, 301; mud volcanoes 311; earthquakes, 327.

J.

James, Sir H., on the shifting of the earth's axis, 8.
James river, 162.
Jan Meyen island, volcanoes, 305.
Japan, sea of, 127; hot springs, 205; volcanoes, 307; mud volcanoes, 311.
Java, its volcanoes, 306; rich in fruits, 342; reptiles, 369.
Jaxartes, river, 167.
Jorullo, Mexico, quoted by Humboldt, 313.
Julian Alps, 76.

K.

Kakabika falls, 187.
Kamtchatka, volcanoes of, 308; earthquakes, 322.
Kenia, mount (Africa), 89.
Kerman, plains of, 105.
Kertch, mud volcanoes near, 310.
Kilauea crater, 295.
Kilima-njaro (Africa), 89; snow-line on, 189.
Killarney lakes, 173.
Kinzig, river, 163.
Kissingen, intermittent springs of, 215.
Kistna, river, 155.
Kjölen range, 80.
Knots in mountain chains, 92.
Koh-i-kwajeh, lake, 178.
Kosciusko, mount (Australia), 96.
Kuban, river, 157.
Kuen-lin mountains, 86.
Kur, river, 166.
Kurile islands, earthquakes of, 322.

L.

Labyrinthodon, 405.
Laccadives, 70.
Ladak, level at, 105.
Ladoga lake, 176.
Lahn river, 155.
Lagoons, 171.
Lake Champlain, 182; Erie, 182; Garda, 174; Huron, 182; Michigan, 182; Nicaragua, 183; Okechobee, 182; Ontario, 182; Pontchartrain, 182; St. Clair, 182; Superior, 181; Titicaca,

183; Van, 178; earthquake band through, 322.
Lakes, position of, 66; Alpine, 76; general account of, 169.
Lancashire moors, rain-fall, 260.
Land, 57; of Europe and Asia, 66; of Africa and America, 67; of Australia, 68; animals, 366; plants, in Silurian rocks, 386.
Land springs, 202.
Landes, sand hills of, 438.
Lapillæ, or volcanic dust, 297.
La Plata basin, earthquakes of, 327.
Las Trincheras springs, 214.
Laurels, home of, 339.
Laurentian schists, 44.
Lava, sub-aqueous, 37.
Law of species, not known, 384.
Lead ores in limestone, 50.
Leeds rain-fall, 261.
Leicester rain-fall, 261.
Lelinga river, 177.
Lena river, 166.
Length of axis of lands of Old World, 63.
Lepidodendron, 387.
Lepidotus, fossil fish so called, 401.
Leuk springs, 204.
Lias, 49.
Lichens, 336; home of, 339.
Life, a result of force, 19; how related to forms of force, 28; succession of, '33; indications of in all stratified rocks, 42; of the earth, its nature, 52; its relation to air, 232; co-existent with the universe, 333; universal, 384.
Light, an undulation of atoms, 23; its waves different from sound-waves, 23; its absorption in passing through air, 225.
Lightning, 242.
Limestones, metamorphosed, 50; springs in, 203.
Limits of land and water indeterminate, 73.
Limits of an earthquake, 321.
Limits of certain kinds of vegetable life, 338.
Lincolnshire, effects of the drainage of the fens on climate of, 430.
Linear volcanoes, 315.
Line of no variation, 30.
Line of coast, important, 62.
Lipari islands, 302.
Lippe river, 155.
Lisbon, earthquake of, 318, 329.
Lithium, not rare in mineral waters, 211.
Little Russia, steppes of, 110.
Liverpool rain-fall, 260.
Lizards, distribution of, 371.
Llanos, of the Orinoco, 114; proper 116.
Lodes or metallic veins, 35.
Lodora springs, contents of, 211.
Lofty plains or plateaux, 66.
Loire river, 155.
Lombardy, irrigation in, 434.
Looming, 230.
Los Pastos, knot of, 95.
Low Archipelago, 69.
Low plains, 108.
Loxas, knot of, 94.
Lucerne, lake, 173.
Lugano, lake, 174.
Lungern-see, 173; drainage of, 433.
Luzon, intense earthquake action at, 322.
Lyell, Sir C., his theory of volcanoes, 313.

M.

MACKENZIE river, 166.
Mackerel sky, 251.
Machairodus, 418.
Madagascar, mountains of, 89; vegetation of, 347.
Mäelström, 147.
Magdalena river, 160.
Maggiore, lake, 174.
Magnesian salts, 212.
Magnetic axis, of the earth, 29.
Magnetic intensity, changes in, 31.
Magnetic metals, 30.
Magnetic needle, phenomena of, 30, 31.
Magnetic storms, 31, 243.
Magnetism produced by electricity, 27; of iron, 29.
Magnets, their various uses, 30.

Magnitude of the earth, 3.
Main equatorial current, 146.
Maine river, 155.
Malar lake, 176.
Maldives, 70.
Maledetta, mount (Pyrenees), 77.
Mallet, Mr., his report on earthquakes referred to, 300, 322.
Malta, curious result of digging through the roof of a cavern in, 440.
Malva, plateau, 105.
Malvern hills, 98, 99.
Mammalia, extinct, 417.
Mammals, distribution of, 375; fossil chiefly in tertiary rocks, 415.
Manasa, level at lake of, 105.
Manatee, habit of, 357.
Man, introduction of, 355; early indications of, 418; his influence on inanimate nature, 421.
Marañon river, 160.
Mare's tail sky, 251.
Marine animals, distribution, 355; saurians, 407.
Marine vegetation, 351.
Marquesas islands, volcanic, 307.
Marram, the English name of *Arundo arenaria*, 439.
Marsh, Mr., his work, "Man and Nature," 421.
Marsupial quadrupeds, 377.
Mass of the air, 222.
Masses of land of different axial direction, 63.
Material elements of the earth, 8.
Matter, wide extension of, 2.
Mauna Loa (crater), 295.
Mauritius, recently extinct birds of, 412.
Maury, Capt., his illustration of the freezing of salt water, 136.
Measurements of the earth, 57.
Mediterranean Sea, 126; state of the water, 134; earthquakes of, 327; flora of the coasts, 349.
Medusæ, habits of, 364.
Megalichthys, fossil fish so called, 401.
Megalosaurus, 408.
Memel river, 154.
Menam river, 164.
Messina, loss of life during an earthquake in, 318.
Metals, most important, 11; good conductors of heat, 22; relative conductive powers, 22; magnetic and dia-magnetic, 30.
Metamorphosis, 49.
Meteorites, 1.
Meteors, 1, 244.
Meteorologist, work of, 287.
Mexican gulf, 127.
Mexico, mountains, 90; northern part almost rainless, 262; volcanoes, 308; destruction of life in an earthquake, 318; limits of palm on its mountains, 339; flora of, 346.
Michigan lake, 182.
Migration, of all kinds, dependant on geographical position, 121; of plants, under circumstances now impossible, 340; of insects, 368;
Mineral springs, 203; contents of, 206.
Mineral veins, 35.
Minerals that make up rocks, 33.
Mines, changes on surface produced by working them, 441.
Mirage, common in the desert, 113; general account of, 228; indicative of change in weather, 230.
Mississippi, valley, 102; river, 161.
Missouri river, 161.
Mist, how produced, 248.
Mistral, increase of near the mouth of the Rhone, when the Cevennes forests were removed, 435.
Mixture, not combination, 15.
Mobile river, 162.
Mock suns, 252.
Mode of action of forces, 19.
Modena, change of climate owing to the removal of forest, 425.
Moldau river, 154.
Molecular change produced by force, 28.
Molecular transfer, rate of in various bodies, 22.

Mollusca, distribution of, 362; fossil, 391.
Moluccas, their quadrupeds, 377.
Monkeys, fossil, 418.
Monocotyledons, 336.
Monsoons, 239.
Mont Blanc (Alps), 75.
Monte Cormo (Apennines), 80.
Monte Nuovo, 304.
Monte Rosa (Alps), 75.
Monte Vulture (Apennines), 301.
Moon, its position in space, 3; distance and magnitude, 4; cause of its partial illumination, 226; influence of on earthquakes, 328.
Moraines, 194.
Morave river, 157.
Morumbidgee river, 165.
Moselle river, 155.
Mosses, 336; home of, 339.
Motion, not limited to masses, 2; results of, 2; of matter in space, 2; of earth affected by moon and planets, 6; produces heat, 19, 21; light as a form of, 23; of atoms producing waves, 24; produced by electricity, 27; chemical action a form of, 27; of glaciers, 194; of the air, 236; of clouds, 255.
Motive power developed in electricity, 23.
Mountains, 74; definition of, 97.
Mount, Argæus (Armenia), 83; Brown (Rocky Mountains), 91; Cook (New Zealand), 96; Egmont (volcano), 307; Elburz (Caucasus), 82, 304; Elias (Rocky Mountains), 91; Fareweather (Rocky Mountains), 91; Guioma (Pindus), 78; Hooker (Rocky Mountains), 91; Kosciusko (Australia), 96; Maledetta (Pyrenees), 77; Tatra (Carpathians), 78.
Mountain chains, 74; sources of rivers, 152; divide weather, 279; barriers, preventing migration of animals, 367.
Mountain lakes, their removal affects climate, 433.
Mountain slopes, 70.
Mozambique current, 147.
Mud volcanoes, 309.
Muley Hacen (Spain), 81.
Mull, island of, rain-fall, 260.
Multilocular shells, 365.
Murchison falls, 186.
Murray river, 165.
Mussels, distribution of, 392.
Mustakh, glaciers of, 197.
Mylne, Mr., on Scottish earthquakes, 326.
Myrtles, home of, 339.

N.

Native sulphur, 208.
Natural combinations of elements, 11.
Natural provinces, 382.
Nature, human influence on, 421.
Neckar river, 155.
Néris, waters of, 203.
Neuchatel lake, 174.
Neusiedler-see, 175.
Neutral points in the atmosphere, 234.
Neva river, 154.
Névé, 193.
New Guinea, 69; mountains of, 96.
New red sandstone, fossils of, 410.
New Zealand, 69; glaciers, 96, 197; mountains, 96; volcanoes, 307; fossil birds, 411.
Niagara falls, 186.
Nicaragua lake, 183.
Niemen river, 154.
Nickel at Boulou springs, 213.
Nicobar islands, volcanoes of, 306.
Niger river, 159.
Nile, its sources, 151; river, 158; earthquake band through basin of lower, 322.
Nimbus clouds, 253.
Nitrogen gas, 12; in spring waters, 207.
Noises accompanying earthquakes, 319.
Norfolk, rain-fall, 261.
Noric Alps, 76.

Norska Fjellen, 80.
North America, coast line, 65; lakes, 181; earthquakes, 327.
North-east and north-west monsoons, 240.
North Sea, state of the water, 135.
Northern Asia has Arctic vegetation, 350.
Norway, waterfalls, 184; glaciers, 197.
Nyanza lakes, 179.
Nyassa lake, 180.

O.

Oases in the desert, 113.
Oaze, the Atlantic mud, 131.
Obe river, 165.
Ocean, the, 125.
Ocean floor, knowledge of, 129.
Oceanic basins, 128.
Oceans, determined by protuberance of land, 60.
Ohio river, 161.
Oil, springs of, 210.
Olotte, springs, 204.
Onega, lake, 176.
Ontario, lake, 182.
Oolitic rocks, 47; vegetation on, 387.
Opposing winds, result of, 271.
Orange river, 159.
Orchids of Java, 342.
Oregon river, great basin of, 107; account of, 165.
Ores of iron in limestone, 50.
Organic contents of rocks, 46, 390.
Organic matter in springs, 213; in volcanoes, 313.
Origin, of water supplies, 218; of volcanoes, 313.
Orinoco river, connected with Amazons by natural canals, 152; account of, 160.
Oscillations of atoms, simple or compound, 23.
Oscillations of barometer, 223.
Ostud-foss, waterfall, 185.
Ouse river, 155.
Owen, Professor, quoted, 397, 420.
Owhyee. *See* Hawaii, 295.
Oxus river, 167.
Oxygen gas, 11.
Oysters, distribution of, 392.
Ozone, its effect on the air, 25; renders air opaque to heat, 25; account of, 272; its influence on weather, 284.

P.

Pacific Ocean, islands of, 69; general account of, 127; bottom of, 132; its currents, 147; trade winds of, 241; reptiles of, 358; mud of, composed of foraminifera, 389; South, confervæ in, 352.
Pack-ice, 191.
Palæontology, its meaning, 32, 379.
Palæotherium, 416.
Palæozoic rocks, 45.
Palgrave, Mr., his account of the Arabian desert, 113.
Palms, home of, 339; value of, in checking the advance of sand, 436.
Pampas, 115, 117.
Pandanus, a characteristic tree, 344.
Pantelleria, island of, 302.
Para river, 160.
Paraguay river, 159.
Paramos, or frozen plains of the Andes, 92.
Parana river, 159.
Parhelia (mock suns), 252.
Paris, built of fossil foraminifera, 389.
Parma, change of climate owing to removal of forest, 425.
Pasco, knot of, 94.
Passes of the Alps, 75.
Patagonia, Andes of, 93; steppes, 108; volcanoes, 307.
Paternó, mud volcano, 309.
Patos lake, 183.
Patrington, rain-fall, 261.
Peaks of the Alps, 75.
Penguins, habits of, 357.
Pentacrinites, fossil, 390.
Periodic changes of climate, 289.

Periodical rains, 259.
Permanence, in nature, 384.
Permian period, rocks of, 46; glacial action during, 200.
Perrey, Professor, on distribution of earthquakes, 323.
Persia, table lands of, 104; desert almost rainless, 262; yields several fruits cultivated in England, 349.
Petrel, habit of, 357.
Peru, Andes of, 94; volcanoes, 307.
Petchora river, 165.
Phillippine Islands, 307.
Phlægrean fields, 363.
Phosphatic fossils, 417.
Phosphorus, 13.
Physical features of the earth, 61.
Physical forces, account of, 18; exerted in evaporation and condensation of rain, 262.
Physics, its importance in physical geography, 29.
Piazza Torre, devastation of wood changing the climate, 425.
Pilate Mount, clouds on, 251.
Pindus chain, 78.
Pine barrens, 114.
Pines, home of, 339; limit of, 340.
Plains, 66; elevated, 102.
Planets, 1.
Planting, a great protection to dunes, 439.
Plata, La, estuary of, 159.
Plateaux, 61, 102.
Platinum, a bad conductor of electricity, 22.
Platten-see, 175.
Plesiosaurus, 407.
Pliosaurus, 407.
Plombiéres springs, contents of, 208; confervæ at, 214; change in mineral contents of water, 217.
Po, river, 157.
Polar current, 147.
Polar forces, meaning of, 29.
Polarisation of light, 233.
Pontchartrain lake, 182.
Ponza islands, 363.
Poole, 170.
Popocatepetl (volcano), 308.
Popayan springs, iron at, 213.
Porco, knot of, 94.
Porphyry, its nature, 36.
Position, geographical, affecting climate, 270.
Potash rare in waters, 211.
Potomac river, 162.
Potosi, knot of, 94.
Potsherds, vast multitudes round old cities, 441.
Prairies, 114.
Pressure in deep water, 137.
Pressure of the air, 221; an element of climate, 269.
Prismatic spectrum, as seen in the higher part of the atmosphere, 234.
Prognostications of weather, 281.
Protozoa fossil, 388.
Provinces, of marine vegetation, 35; natural, 382; geological, 418.
Pruth river, 157.
Pterichthys, a remarkable fossil fish, 400.
Pterodactyl, 408.
Pullna, magnesian salts at, 212.
Purity of ice, 191.
Putrid sea, how produced, 311.
Pyäjärvi lake, 176.
Pyramidal form of land, 63.
Pyramids, the, built of fossil foraminifera, 389.
Pyrenean chain, 77.
Pyrenees, hot springs of, 205.
Prognostications of weather only possible a short period in advance, 287.

Q.

QUADRUPEDS, distribution of, 375; fossil remains of, 413; extinct, 417.
Quantock hills, 100.
Quarrying of granite, 35.
Quito, Andes of, 95; volcanoes, 307; great earthquake at, 318.
Quorra river, 159.

R.

RAAB river, 157.
Radiata fossil, 390.
Radiation, of heat from aqueous vapour, 26; of motion from the earth, 29; its general results, 246.
Radiant power of light, 23.
Rain, production of, 258; without cloud, 263; influence of forest on fall of, 426.
Rainbow, 231.
Rain-clouds, 253.
Rain-fall, of British Islands, 259; total on the earth, 264; in its relation to climate, 271; sometimes continuous over a large area, 279.
Rainless regions, 262.
Range of fossils, 391.
Range of temperature, an element of climate, 267.
Rate of conduction of metals, 22.
Ravanabrada, level at lake of, 105.
Ravenna, effect of removing pine forests of, 425.
Ray, its appearance, 359.
Reconstructed rocks, 49.
Red crag and its contents, 417.
Red river, 161.
Red Sea, evaporation from, 144; volcanoes of, 304; confervæ in, 352.
Reflection of light in the air, 227.
Refraction, ordinary, 226; unusual, 228; double, 233.
Regelation, property of, 195.
Regen river, 157.
Regions, botanical, 338; of marine vegetation, 351; of depth in distribution of animals, 355.
Rennel's current, 147.
Representative forms of plants, 340.
Representative quadrupeds of South America, 378.
Reptiles, distribution, of marine species, 358; of land species, 369; absence of in certain islands, 372; fossil, 405, 409.
Revolution of planets, 3; of the earth, 5.
Rhine, valley, 101; river, 154; falls of the, 184; extinct volcanoes of, 314; basin, earthquakes of, 327.
Rhododendrons, home of, 339; limit of, 340.
Rhone, river, 156; valley, ice scratches in, 197.
Rhynchonella, distribution of, 392.
Rhynchosaurus, 408.
Rigidity of the earth's crust, 8.
Rio Bambo earthquakes, 317.
Rio (river) Bravo del Norte, 161; Grande, 161; Negro, 160; Vinagre, sulphuric acid at, 208.
Ripon falls, 186.
Ripple, 140.
Riukan-fos (waterfall), 185.
Rivers, 149.
Rivers traversing the steppes of Asia, 111.
River systems, 150.
Roanoake river, 162.
Roches moutonnées, 196.
Rock oil, springs of, 210.
Rock salt, diathermic, 25.
Rocks, succession of, 32.
Rocky Mountains, slopes of, 71, 90.
Rome, snow at, 190.
"Royal Charter" storm, 243.
Ruhr river, 155.
Ruskin, Mr., his account of rain-clouds, 254.

S.

SAALE river, 154.
Sacramento river, 165.
Sahara, plain of, 113; prevalent winds of, 241; almost rainless, 262.
Salses, 309.
Salt, quantity of in the sea, 133; deposits in lakes, 171; absent in ice, 191.
Salt lakes, 172.
Saltness of the sea, 132.
Samen mountains (Africa), 89.

Sand, its heat-retaining power as a soil, 424.
Sands, moving, 436.
Sand hills very valuable for shelter, 436.
Sandstones, how metamorphosed, 50.
Sandwich Islands volcanic, 307; flora of, 347.
Santorin eruption, 37, 364.
Saône river, 156.
Sargasso sea, 148.
Sarmatian plains, 103, 110.
Sarnen-see, 173.
Sarp-fos (waterfall), 184.
Saskatchevan river, 166.
Sassuola, mud volcanoes of, 311.
Savannah river, 162.
Savannahs, 114.
Save river, 157.
Saurians, marine, 407.
Saxon Switzerland, 100.
Scandinavian mountain chain, 80; peninsula, earthquakes of, 326.
Scawfell, glacial action in, 198.
Scenery of the Alps, 75.
Scents, effect of on the air, 25.
Schaffhausen, falls of, 184.
Scha-ho desert, 105.
Scha-mo desert, 105.
Schlangenbad, mineral springs of, 203.
Schists, their nature, 38.
Schiwelutch, volcano, 308.
Science, its objects, 443.
Scirocco increased in Italy since the Apennines were cleared of wood, 425.
Scotch mountains, 81.
Scotland, plateau of, 106; lakes of, 173; rain-fall, 260; earthquakes of, 326, 328; its flora, 348; effect of planting in, 426.
Scratches by ice, 196.
Scrope, Mr. Poulett, his work on volcanoes of Central France, 313.
Saima lake, 176.
Sea of Azof, 126.
Sea of Marmora, 126.
Sea Alps of California, 90.
Sea anemones, habits of, 364.
Sea horse, its habit, 359.
Sea water, 132.
Sea weeds, growth of, 336.
Seal, distribution of, 357.
Season, its meaning, 278.
Seathwaite rain-fall, 260.
Secondary rocks, 46.
Segregation, 41.
Seine river, 155.
Seistan lake, 178.
Selection, natural, a method of nature, 385.
Senegal river, 159.
Sensations, foretel weather, 283.
Serein, its nature, 263.
Sereth river, 157.
Serpentine, fossils in, 44.
Serpents, fossil, 409.
Severn, valley, 101; river, 155.
Shadows of clouds, 256.
Shabel lake, 177.
Sharks, fossil, very common, 398.
Shirwa lake, 180.
Shooting stars, 1.
Sicily, snow line, 189.
Sierra, Madre (Mexico), 90; Morena, 81; Nevada, 81.
Sigillaria, 387.
Silex in mineral springs, 207.
Silica deposited from springs, 209.
Silicified wood, 209.
Silicium, 13.
Silurian rocks, 45; fossil plants in, 386.
Siluroid fishes, 401.
Silvas, 115.
Simeto, mud volcano near the, 309.
Sir river, 167.
Slate, 39.
Sligo, rain-fall, 260.
Slopes of high land, 60; of mountain sides, 70.
Snae Hatten (Scandinavia), 80.
Snails, distribution of, 393.
Snow, its formation, 188.
Snow line, in the Pyrenees, 77; on the Himalayas, 84; of Chilian Andes, 94; its limit, 189.
Snowdon (Wales), 81.
Snowy mountains (Mexico), 90.
Society islands, volcanic, 307.

Soda salts, common in water, 211.
Soils, heat-retaining power of various kinds, 424.
Solar system, one group, 6; account of, 7.
Solfatara, 364.
Solid matter in the ocean, 133.
Sound, phenomena of, 231.
Sound waves, different from light waves, 23.
Soundings, deep, 129.
Sources of rivers, 151.
South America, coast line of, 65; plateaux, 108; plains, 115; rivers, 159; lakes, 183; prevalent winds of, 241; earthquakes, 322; flora of, 343; its birds, 373; quadrupeds, 377.
South Atlantic current, 147.
South Down hills, 99.
South Pacific, confervæ in, 352.
South polar current, 147.
Southern hemisphere, limit of snow in, 189.
Southern trade winds, 239.
Spain, its mountains, 81; extinct volcanoes, 314; earthquakes, 326; its aridity caused by absence of forests, 426.
Special floras, 341.
Species, natural death of, 336, 384; originates at certain centres, 354; first introduction of, 378; derived from varieties, 386; extinction of, 419.
Specific centre, its meaning, 381.
Specific gravity, of rocks supposed to be different in the two hemispheres, 59; of sea water, 133.
Spectrum, derived from a pencil of rays, 23; seen in higher part of the atmosphere, 234.
Spectrum analysis, 9, 27; used in detecting traces of elements, 206.
Spherical form of heavenly bodies, 3.
Spiders, distribution of, 367.
Spiral motion of the air in a storm, 237.
Sponges, distribution of, 366; fossil, 388.
Spree river, 154.
Spring water not pure, 203.
Springs, account of, 201; of rock oil, 210; affected by removing forests, 427.
Sprudel spring, its contents, 206; incrustations, 212.
Star-fishes in deep water, 138; distribution of, 363; fossil, 390.
Stars, connected with the solar system, 6.
Statistics of earthquakes, summary of, 327.
Staubbach falls, 184.
St. Clair lake, 182.
St. Etienne, coal mine burning there, 441.
St. Helena, volcano, 305.
St. Jean de Maurienne (Savoy), earthquakes at, 329.
St. Lawrence, river, 162.
St. Laurent, springs, 204.
Sta. Martha, mountain of, Andes, 95.
St. Vincent, eruption of, 317.
Steel, how made magnetic, 29.
Steppes, 110.
Stonesfield slate, fossil quadrupeds of, 414.
Storms, magnetic, 31; general account of, 241; their effect in clearing the air, 256; affect weather, 280.
Storm-waves, 141.
Strata, and stratified rocks, 41.
Stratification of granite not common, 35.
Stream currents, 145.
Streams, natural, reversed, 435.
Stromboli, volcano of, 302.
Struggle for existence, among plants, 338; the law of nature, 384.
Subdued activity of volcanoes, 309.
Sub-marine eruptions, 364.
Succession, nature of, 385.
Succession of rocks, 32.
Sulphate of soda, deposited from mineral water, 211.
Sulphur, in mineral waters, 208.
Sulphuric acid, in the Rio Vinagre, 208.

Sumbawa, intense earthquake action at, 322.
Summary of earthquake statistics, 327.
Sun, distance from earth, 4; dimensions, 5; a source of heat and light, 24; a centre of force, 28.
Sunset as indicative of weather, 282.
Sunset effects, 256.
Superior, lake, 181.
Super-position of rocks, 33.
Surf, 141.
Surface of the earth, what it includes, 16.
Surinam reptiles, 370.
Suspension of clouds, 251, 256.
Susquehanna rivers, 162.
Sussex rain-fall, 261.
Swell, its nature, 141.
Switzerland, its mountains, 76; hills, 98; lakes, 173; water-falls, 184; earthquakes of, 327.
Syenite, its nature, 36; formed with water, 51.
Syria, loss of life in an earthquake at, 318.

T.

Table-mountain, clouds of, 251.
Taguatága, lake drainage of, 433.
Tagus river, 156.
Taman, mud volcanoes of, 310.
Tanganyika lake, 180.
Tarns, 170.
Tasman glacier, 197.
Tatra, mount (Carpathians), 78.
Taurus chain, 82; volcanic, 304.
Tchad, lake, 170, 180.
Teeth, their abundance and usefulness as fossils, 399; afford early indications of quadrupeds, 414.
Teflis, mud volcanoes near, 310.
Tehany lake, 177.
Temes river, 157.
Temperate and torrid zones, earthquakes most common there, 323.
Temperature, increase of, in the interior of the earth, 7; of the sea, 134; of salt water in freezing, 191; of natural springs, 214; mean, 266.
Teneriffe, upper currents observed there, 238.
Tengiz lake, 177.
Tertiary rocks, 48; vegetation of, 387; birds' remains found in, 411; include remains of many quadrupeds, 415.
Thames, valley, 101; river, 155.
Theiss river, 157.
Thermometer as a weather indicator, 285.
Thian Schan mountains, 86; volcanoes of, 306.
Thibet plains, 105; almost rainless, 262.
Thickness of earth's solid crust, 8.
Thistles of the steppes, 120.
Thompson, Prof. W., on rigidity of rocks, 8.
Thrasymene, lake, 175.
Thun, lake, 174.
Thunder-storms, 242.
Thur, river, 155.
Tiber, river, 156.
Tiberias, lake of, 179.
Tidal movements in air, 269.
Tidal wave derived from the moon, 4; general account of, 140.
Tierra del Fuego, volcanoes, 307.
Tigris river, 163.
Time, distribution of earthquakes in, 323.
Tin-oxide, in water of mineral springs, 213.
Titanic acid in water, 213.
Titicaca, level of lake of, 108; account of lake, 183.
Tocantins river, 160.
Tolima (Andes), 95.
Tombigbee river, 162.
Töplitz, Lisbon earthquake affected the springs, 329.
Torrens, lake, 170, 181.
Torrents diverted in Italy, 435.
Tortoises, distribution of, 371; fossil, 409.

Tourmaline, peculiar in the way it conducts heat, 22.
Trade winds, 238.
Transparency to heat, 25.
Transylvanian mountains, 78.
Tree ferns, home of, 339.
Trees, growth of, 337; of North America, 346; their effect on the atmosphere, 424.
Trent river, 155.
Triassic period, fossils of, 410.
Trilobites, 391.
Trincheras, hot springs of, 205.
Trinidad island (South Atlantic), 305; (West Indies), mud volcanoes, 311.
Tristan da Cunha, 305.
Tropics, plants of, 339; reptiles, 370.
Tschar Dagh (Balkan), its height, 378.
Tset-zse fly, range of, 368.
Tundra (Scandinavia and North Russia), 110.
Turkey, result of irrigation in, 434.
Turrilite, 394.
Turtles in Pacific and Australia, 358; fossil, 409.
Tuscany, carbonate of lime in springs of, 212.
Tyndall, Prof., on the absorption of heat, 26; his work on heat quoted, 20.
Types of all invertebrata found in oldest rocks, 395.
Tyrolese Alps, 76.
Twilight, phenomena of, 227.

U.

Ullswater lake, 172.
Under currents, how produced, 145.
Undulations producing earthquakes, 318.
Uniformity of weather never existed, 289.
United States counter current, 147.
Univalves, fossil, 393.
Unter-see, 147.
Upper currents of air, 238.
Uruguay river, 159.
Ural, mountains, 82; river, 166.
Urumiyah lake, 177.

V.

Vaal river, 159.
Val di Chiana, saved by human contrivances, 435.
Valleys, position of, 66; general account of, 100.
Van lake, 178; earthquake band through, 322.
Van Diemen's Land, earthquake band probably reaches, 323.
Vapour, as a condition of weather, 21; does not allow heat to pass through it, 26; atmosphere of, 256.
Variation of the compass needle, 30.
Varieties, production of, 385.
Vegetable life, its great persistency where possible, 422.
Vegetation, of plains, 120; limits of, 338; marine, 351; fossil, 386.
Veins of granite, 34.
Venezuela, mountain chain of, 95.
Veragua, Cordillera of, 92.
Vermilion water in Red Sea and California, 139.
Vertical elevations comparatively small, 60.
Vesuvius, eruption of ash, 297; account of, 363.
Vibrations producing sound, and those producing light, 24.
Vichy waters, account of, 211; contain fluate of lime, 212; variable spring at, 216.
Victoria-Nyanza lake, 179.
Viejo (volcano), 307.
Vindhya mountains, 87, 106,
Visibility, when obtained in a heated body, 24.
Vistula river, 154.
Vital energy, 19; connected with heat and electricity, 28; a form of force, 333.

Volcanic islands, 68.
Volcanoes.—Definition, 293; distribution on the earth, 298; relative position, 300; special groups, Etna, 301; Vesuvius, 303; Greek islands and Asia Minor, 304; Icelandic, 305; Sandwich islands, 295, 307; South American, 307; marks of decaying activity, 309; extinct, 314; mutual relations of, 315.
Volga river, 166.
Volterra, boracic springs of, 311.
Volume of natural springs varies, 214.
Vŏring-fos (waterfall), 185.
Vosges mountains, 81; effect of removal of forests of, 425.

W.

Waag river, 157.
Waldai hills, 99.
Wales, mountains of, 81, 98; lakes, 173; flora, 348.
Wallace, Mr., his account of the Indo Australian Archipelago, 431.
Wallenstadt lake, 174.
Wallich, Dr., his deep sea dredge, 136: on star-fishes from great depth, 363.
Walrus, distribution of, 357.
Water, permeates rocks at great depths, 7; its importance in the economy of nature, 15; its irregular expansion, 21; not diathermic, 25; its energy as a radiant, 26; found in granite, 37; its influence in metamorphosis, 50; general account of, 125; mineral and thermal, 203.
Water-shed, 150.
Water supply of springs affected by forests, 427.
Waterfalls, 184.
Waterford, rain-fall, 260.
Water-parting, or water-shed, its meaning, 150.
Waves, of sound and light, 23; nature, origin, and force of oceanic, 139; account of tidal, 141.
Wealden rocks, 47.
Weather, affects yield of some springs, 216; account of, 277; changes in do not involve changes of climate, 286; never long the same in temperate climates, 289.
Weathering of hills, 97.
Weight of the air, 222.
Wells, Dr., on dew, 247.
Wenern lake, 176.
Werra river, 154.
Weser river, 154.
West Indian islands, 70; volcanoes of, 308; earthquakes, 327; turtles of, 358.
Westmoreland lakes, 172.
Weter lake, 176.
Whales, how distributed, 356; general notice of, 417.
Whirlpools, 147.
White Nile, 158.
Wildbad spring, 203; contents of, 208; titanic acid there, 213.
Winandermere lake, 172.
Wind currents, 144.
Wind storms, 241.
Wind waves, 140.
Winds, general account of, 236; result of when periodical or opposing one another, 271; affect climate, 274; direction, change, and mode of change, foretel weather, 282; their direction and force affected by the removal of forests, 426.
Winnipeg lake, 181.
Winnipegoos lake, 181.
Wollaston lake, 181.
Wolves, effect of destroying them, 423.
Wood conveyed to a distance has carried with it insect species, 368.
Woodland, quantity of, needed for a country, 429.
Wurm-see, 175.
Wurtemberg, arsenic in the springs, 209.

Y.

YANG-TSE-KIUNG river, 164.
Yates, Mr. Jas., his theory of the cause of irregularity of distribution of land, 60.
Year, length of, 5.
Yellow river, 164.
Yellow sea, 127.
Yenesei rivers, 165.
Yorkshire rain-fall, 261.

Z.

ZAMBESI, river, 163; falls of, 185.
Zante, bitumen at, 210.
Zinc ores in limestone, 50.
Zones of elevation correspond to regions of depths in distribution of animals, 355.
Zurich lake, 174.

THE END.

LEWIS & SON, PRINTERS, SWAN BUILDINGS, MOORGATE STREET, LONDON.

MG
An 84.

This book should be returned to the Library on or before the last date stamped below.

A fine is incurred by retaining it beyond the specified time.

Please return promptly.

CANCELLED

APR 5 '68 H

1914 673